SCIENTIFIC AMERICAN

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Physics Exclusive
Stephen Hawking on the Theory of Everything

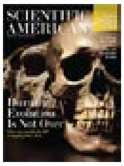
Special Poll
In Science We Trust?

Human Genome
Why the Revolution Is Late

Human Evolution Is Not Over

How our species is still changing over time

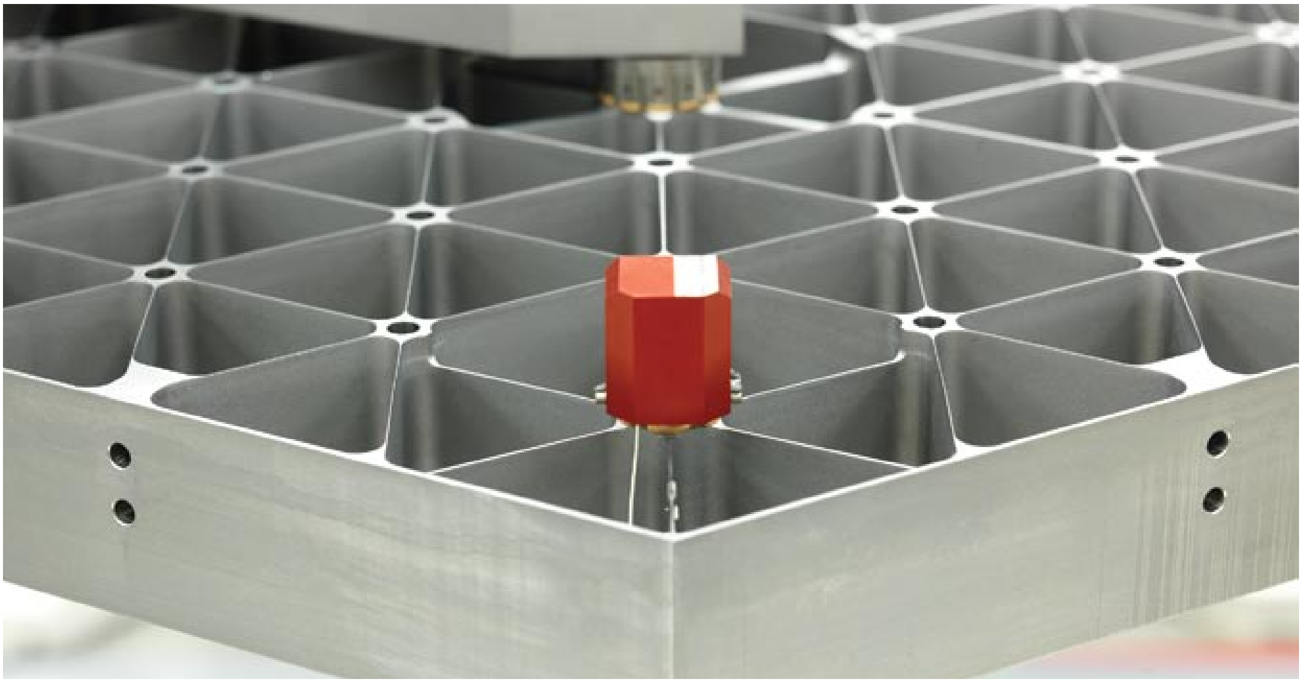
ON THE COVER



Humans are still evolving, but apparently not always in the classic way nor as quickly as some recent findings have suggested. Scientists say that we are thus more likely to combat the problems of the coming millennium with culture and technology than to evolve biological defenses against them. Photograph by Craig Cutler.

SCIENTIFIC AMERICAN

October 2010 Volume 303, Number 4



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FEATURES

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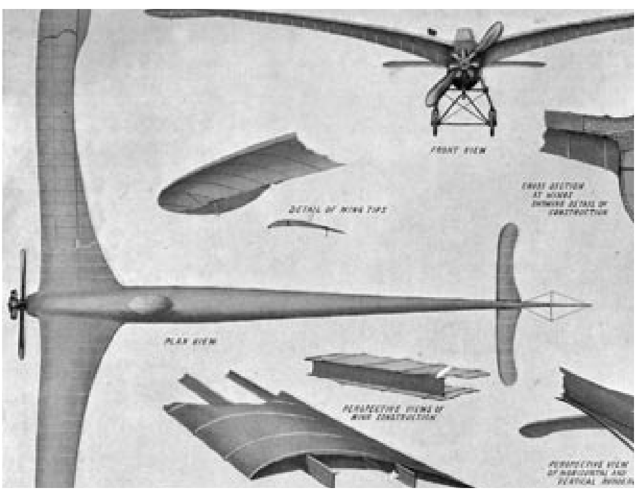

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

Improving Maternal Health across the Globe
Technological, medical and epidemiological advances are allowing more women and children around the world to survive the risks of pregnancy and childbirth.
Go to www.ScientificAmerican.com/oct2010

SCIENTIFIC AMERICAN, VOL. CII, NO. 17; OCTOBER 1910 (*plane parts*)

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Mariette DiChristina is editor in chief of *Scientific American.*

New yet Familiar

Everything evolves. Plant and animal species adapt to their environments. Rocks, under heat or pressure, shift form. Earth revolves around a sun that traces its arc of existence through the ever changing cosmos. And with this issue, *Scientific American* introduces the latest design and content adjustments in its 165-year history, ready to embrace the next 165.

Longtime readers will see much that is familiar in the magazine and its Web site, www.ScientificAmerican.com, from the classic design to the hallmark informational graphics. As always, collaborations with scientists—as authors of the feature articles and as sources for top journalists—inform everything we do.

In recent months we have explored what improvements we could add to *Scientific American*'s traditional strengths, to make its print and digital editions more useful for readers.

You made it clear that the feature articles are important to your relationship with *Scientific American*. You want to dive deep into the science in some articles but also enjoy some shorter pieces. You want a variety of topics, from basic research to technologies, from physical sciences to life sciences. This issue delivers: in our cover story, biologist Jonathan K. Pritchard tells us "How We Are Evolving" (*page 22*). Physicists Stephen Hawking and Leonard Mlodinow describe "The (Elusive) Theory of Everything" (*page 50*). Other articles look at the wonder of an octopus sucker (*page 60*), the challenge of designing ethical robots (*page 54*), the true value of the Human Genome Project (*page 42*), the tribulations of parents with autistic children (*page 62*) and the production of fuels using "artificial photosynthesis" (*page 68*).

We know science's role is important to you. So in a first, we created an exclusive poll on attitudes about science. We worked with *Scientific American*'s 14 international editions around the globe and with our sister publication, *Nature,* the weekly international journal of science, to conduct the poll online. Don't miss "In Science We Trust," on page 38.

We have sharpened the monthly departments as well. In Science Agenda, the Board of Editors analyzes a top science issue, while an expert comments on another critical policy area in Forum. The new Advances provides tightly written updates on key developments in science and technology. In response to readers' interests in personal well-being and in technology's influence on their lives, we introduce The Science of Health (*page 18*) and TechnoFiles (*page 20*), from best-selling author and *New York Times* columnist David Pogue. Last, punctuating each issue is a new back-page column, Graphic Science, which tells a story about a complex topic through a powerful informational graphic. As always, we are eager for your thoughts and reactions. SA

Illustration by Nick Higgins

June 2010

MILKY WAY TIME

In "Is Time an Illusion?" Craig Callender discusses the difficulty of telling if two events are simultaneous or not and thus of establishing a universal, standard measure of time. This argument always seems unconvincing to me. We know how fast our galaxy is rotating, we know our sun's position and velocity, and we know Earth's position and velocity. It seems to me that we could easily define a "Milky Way Standard Time" much as was done when we agreed on Greenwich Mean Time way back in the late 1800s, which made it easy to decide what time it was in California when something happened at a certain time in Chicago. By the same token, but with more to calculate than just a difference in longitude, it should be possible to compute the Milky Way Standard Time when two events occurred and determine if they were really simultaneous or not. Does this make the problem go away?

When discussing past-to-future slicing of spacetime, Callender also writes that "the data you need … are fairly easy to obtain. For instance, you measure the velocities of all particles." But Heisenberg's uncertainty principle puts definite limits on how accurately one can measure the position and velocity (or momentum) of a particle. It is a very important limitation, and it seems to me that the entire argument falls apart at this point.

Crawford L. Sachs
Oxnard, Calif.

"We could define a 'Milky Way Standard Time' much as we agreed on Greenwich Mean Time."

CRAWFORD L. SACHS *OXNARD, CALIF.*

CALLENDER REPLIES: Saying that events are "really simultaneous" suggests that physics, or nature, prefers one foliation of spacetime—and thus one convention for what events are simultaneous or not—over others. But that preference in this case is really yours, not nature's. A "Milky Way Standard Time" might be a good choice locally, if only as an approximation (the galaxy is not a rigid body). But because according to general relativity spacetime is curved, there is no standard way to extend a local foliation to the entire universe.

A better choice might be to take the cosmic microwave background to be the definition of what is "at rest" and use that frame of reference to synchronize clocks. Either way, the theoretical problem of time does not go away. There always exist coordinate systems that will make two spacelike-related events happen "at the same time." Relativity states that no such system is the "right" one.

The point about the uncertainty principle is one that deserves some further study. Indeed, in quantum mechanics we have not only practical but also in-principle limitations on what information we can gather across space at a moment.

Callender lucidly writes that as money is one way to describe the relation between disparate objects, so is time. That eminent experimenter Benjamin Franklin would be pleased to learn that in the physical, as well as financial world, "time is money."

Doug McKenzie
Palo Alto, Calif.

COSMETIC CHANGES

"Fake Botox, Real Threat," by Ken Coleman and Raymond A. Zilinskas, should perhaps have been headed "Fake Threat, Real Botox." Botox is sold in vials containing 100 units, or 4.8 billionths of a gram, of toxin. To accumulate the deadly dose of 70 micrograms of botulinum neurotoxin (BoNT) from cosmetic sources would require purchasing more than 14,000 vials. For the toxin to be lethal, a person would have to drink more than 145 liters of the liquid. And even a highly discounted price would likely be excessive. Why would a terrorist even consider buying cosmetic Botox when the authors suggest they could make it themselves?

Sydney Bird
Guelph, Ontario

THE AUTHORS REPLY: Our article focused solely on current, and probable future, illicit manufacturers of counterfeit BoNT products. Nowhere in the article do we even hint that legitimate manufacturers, or their products, pose a security threat. As we wrote, referring specifically to the market for illegal BoNT and to its makers and distributors: "From a security perspective, this booming market is troubling because for manufacturer-distributors it is only a small step from selling counterfeit BoNT products for cosmetic uses to selling the botulinum toxin itself in bulk quantities directly to subversive interests." To reiterate, our concern is that anyone with a credit card and access to the Internet, including criminals and terrorists, can contact illicit manufacturers of BoNT, purchase gram quantities of it and have the purchase delivered to an address of their choice. This is a new proliferation development that we have found is not being addressed by security agencies or international law and therefore needs to be publicized.

ONE BODY, MANY PROBLEMS

In "Asteroid Collision" ["12 Events That Will Change Everything"], Robin Lloyd discusses how to realistically prevent an asteroid or comet from impacting a high-value target on Earth. She cites the idea of slightly altering the path of the incoming object, using either a kinetic impactor or a nuclear charge. The menace might thus be diverted from, say, a megalopolis, or made to miss Earth altogether. But there's a catch: the farther the object, the smaller the necessary nudge, yet the greater the uncertainty in predicting the point of impact. Given the notorious chaotic nature of the long-term gravitational many-body problem, a far enough slight nudge

calculated to save a city might inadvertently end up turning a would-be comfortable miss into an actual bull's-eye, might it not?

Dov Elyada
Haifa, Israel

LLOYD REPLIES: In the general many-body problem, it is indeed hard to make predictions. Here, however, the near-Earth object is too small to affect the orbits of the planets. Thus, it is just one body moving in a predictable environment. The hard part is to know how much of a nudge to give an object, because its properties, such as its mass, are difficult to measure from afar.

GOSSIP VS. SCIENCE

I am a longtime subscriber to *Scientific American* and enjoyed your June issue. But political satire as exemplified by Steve Mirsky's "Presidential Harrisment" [Anti Gravity] seems out of place in the magazine. Mirsky usually makes an effort to have at least a tenuous tie-in to science, but even that is missing this month. You might as legitimately have a gossip column, sports results, wine comparison or travel log. Perhaps Mirsky should seek a position in one of the many fine publications devoted to politics.

William S. Haney
Onancock, Va.

MIRSKY REPLIES: The column was not about politics. It was about rationality, a necessary part of scientific thinking.

ERRATA

Because of an editing error, Kei Hirose's "The Earth's Missing Ingredient" describes the compound $UFeS_3$ as uranium ferrous sulfate; it is uranium ferrous sulfide.

The caption in the photograph accompanying Bob Roehr's "Bad Wraps on Viruses" [News Scan] suggests that adenoviruses have a lipid coat. They do not.

In "Asteroid Collision" ["12 Events That Will Change Everything"], Robin Lloyd states that Meteor Crater is in Barringer, Ariz. The correct location is near Winslow, Ariz.

"Fake Botox, Real Threat," by Ken Coleman and Raymond A. Zilinskas, states that one unit of botulinum neurotoxin equals 4.8 nanograms. The correct conversion is that 100 units equal 4.8 nanograms.

LETTERS TO THE EDITOR

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/oct2010

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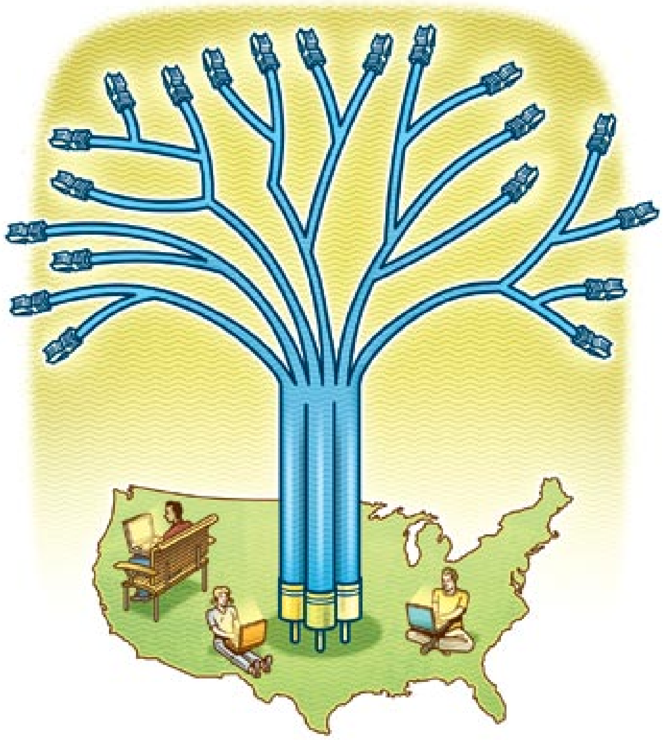


Competition and the Internet

Why broadband service in the U.S. is so awful, and one step that could change it

The average U.S. household has to pay an exorbitant amount of money for an Internet connection that the rest of the industrial world would find mediocre. According to a recent report by the Berkman Center for Internet and Society at Harvard University, broadband Internet service in the U.S. is not just slower and more expensive than it is in tech-savvy nations such as South Korea and Japan; the U.S. has fallen behind infrastructure-challenged countries such as Portugal and Italy as well.

The consequences are far worse than having to wait a few extra seconds for a movie to load. Because broadband connections are the railroads of the 21st century—essential infrastructure required to transmit products (these days, in the form of information) from seller to buyer—our creaky Internet makes it harder for U.S. entrepreneurs to compete in global markets. As evidence, consider that the U.S. came in dead last in another recent study that compared how quickly 40 countries and regions have been progressing toward a knowledge-based economy over the past 10 years. "We are at risk in the global race for leadership in innovation," FCC chairman Julius Genachowski said recently. "Consumers in Japan and France are paying less for broadband and getting faster connections. We've got work to do."

It was not always like this. A decade ago the U.S. ranked at or near the top of most studies of broadband price and performance. But that was before the FCC made a terrible mistake. In 2002 it reclassified broadband Internet service as an "information service" rather than a "telecommunications service." In theory, this step implied that broadband was equivalent to a content provider (such as AOL or Yahoo!) and was not a means to communicate, such as a telephone line. In practice, it has stifled competition.

Phone companies have to compete for your business. Even though there may be just one telephone jack in your home, you can purchase service from any one of a number of different long-distance providers. Not so for broadband Internet. Here consumers generally have just two choices: the cable company, which sends data through the same lines used to deliver television signals, and the phone company, which uses older telephone lines and hence can only offer slower service.

The same is not true in Japan, Britain and the rest of the rich world. In such countries, the company that owns the physical infrastructure must sell access to independent providers on a wholesale market. Want high-speed Internet? You can choose from multiple companies, each of which has to compete on price and service. The only exceptions to this policy in the whole of the 32-nation Organization for Economic Co-operation and Development are the U.S., Mexico and the Slovak Republic, although the Slovaks have recently begun to open up their lines.

A separate debate—over net neutrality, the principle that Internet providers must treat all data equally regardless of their origin or content—has put the broadband crisis back in the spotlight. Earlier this year a federal appeals court struck down the FCC's plan to enforce net neutrality, saying that because the FCC classified the Internet as an information service, it does not have any more authority to ensure that Internet providers treat all content equally than it does to ensure that CNN treats all political arguments equally. In response, the FCC announced its intention to reclassify broadband Internet as a telecommunications service. The move would give the FCC power to enforce net neutrality as well as open broadband lines up to third-party competition, enabling free markets to deliver better service for less money.

Yet, puzzlingly, the FCC wants to take only a half-step. Genachowski has said that although he regards the Internet as a telecommunications service, he does not want to bring in third-party competition. This move may have been intended to avoid criticism from policy makers, both Republican and Democrat, who have aligned themselves with large Internet providers such as AT&T and Comcast that stand to suffer when their local monopolies are broken. It is frustrating, however, to see Genachowski acknowledge that the U.S. has fallen behind so many other countries in its communications infrastructure and then rule out the most effective way to reverse the decline. We call on the FCC to take this important step and free the Internet. SA

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/oct2010

Illustration by Peter and Maria Hoey

Melissa Hathaway led President Obama's Cyberspace Policy Review and is now a member of the board of directors of the EastWest Institute, a nonprofit think tank.

Power Hackers

The national smart grid is shaping up to be dangerously insecure

President Barack Obama's talk about the need for a "smart grid" sounds, well, smart. What's not to like about the idea of an electricity grid that can work at top efficiency? By wrapping power transmission lines in advanced information technologies and the Internet, a smart grid would enable us to integrate alternative energy sources such as rooftop solar panels and local wind turbines into the power supply, balance supply with demand and optimize the flow of power to each consumer—even down to the level of individual appliances. It would vastly improve the reliability, availability and efficiency of the electric system. As currently envisaged, however, it's a dangerously dumb idea.

The problem is cybersecurity. Achieving greater efficiency and control requires hooking almost every aspect of the electricity grid up to the Internet—from the smart meter that will go into each home to the power transmission lines themselves. Connecting what are now isolated systems to the Internet will make it possible to gain access to remote sites through the use of modems, wireless networks, and both private and public networks. And yet little is being done to make it all secure.

The grid is already more open to cyberattacks than it was just a few years ago. The federal government has catalogued tens of thousands of reported vulnerabilities in the 200,000-plus miles of high-voltage transmission lines, thousands of generation plants and millions of digital controls. Utilities and private power firms have failed to install patches in security software against malware threats. Information about vendors, user names and passwords has gone unsecured. Logon information is sometimes unencrypted. Some crucial systems allow unlimited entry attempts from outside.

As the power industry continues to invest in information technology, these vulnerabilities will only get worse. Smart meters with designated public IP addresses may be susceptible to denial of service attacks, in which the devices are overwhelmed with spurious requests—the same kind of attacks now made on Web sites. Such an attack could result in loss of communication between the utility and meters—and the subsequent denial of power to your home or business.

The smart grid would also provide hackers with a potential source of private information to steal. Just as they use phishing attacks to elicit passwords, credit-card numbers and other data stored on home computers, hackers could find ways of intercepting customer data from smart meters. A sophisticated burglar might use these data to figure out when you're away on vacation, the better to rob your house.

Customer data could also give hackers a way to bring down the grid. Smart meters injected with malware, for instance, could disrupt the grid just as networks of PC botnets—home computers hijacked by viruses—now disrupt the Internet. A network of drone smart meters could cause a swath of the grid to power down, throwing off the grid's electrical load. The imbalance would send large flows of electricity back to generators, severely damaging them or even blowing them up.

A smart grid isn't a bad idea if we build cybersecurity into it from the start. But we're not doing that. Under the smart grid funding programs, part of the fiscal stimulus package, the government has released $3.4 billion for a nationwide smart grid and plans to spend more than $4 billion more, but the Department of Energy has only recently begun to address the security requirements. So far utilities have been so focused on tamping costs that they haven't been willing to pay for robust across-the-board security measures. Regulation alone won't be enough.

What we need is a partnership among the standards setters, the regulators and industry to build security into the system from the ground up. These measures would include procedures for assessing the security of smart grid devices and other systems, for certifying personnel and business processes, and for compensating power companies for their security investment. We also need more research into improving the security of computer chips and other hardware that gets installed in the grid. We need a plan to deal with grid failures. We need international cooperation and research into forensic technology to deal with attacks from abroad. The energy sector could take a page from financial firms, which do a good job of ensuring that Internet-based transactions are secure. We do not need to abandon the idea of a smart grid. But we need to be much smarter in planning it—with cybersecurity as a key element, not an afterthought. SA

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/oct2010

Illustration by John Hersey

Starburst: The remains of a supernova, as captured in a composite image by three NASA telescopes.

Astronomy

The Biggest Bang Theory

A new type of supernova is forcing astronomers to rethink the lives of the biggest stars

When our sun comes to its ending in five billion years or so, it will fade into a quiescent white dwarf. Bigger stars go out with a bang—those with more than 10 times the mass of our sun collapse with enough vigor to spark a supernova, one of the most energetic events in the universe. For decades astronomers have suspected the existence of a type of stellar explosion that is bigger still—a "pair-instability" supernova, with 100 times more energy than an ordinary supernova. In the past year two teams of astronomers have finally found it, redrawing in a stroke the limit of how big things can be in this universe of ours.

All stars balance gravity with pressure. As light elements such as hydrogen fuse in a star's core, the reactions generate photons that press outward, counteracting the pull of gravity. In larger stars, pressure at the core is high enough to fuse heavier elements such as oxygen and carbon, creating more photons. But in stars bigger than 100 solar masses or so, there's a hitch. When oxygen ions begin to fuse with one another, the reaction releases photons that are so energetic, they spontaneously transmute into electron-positron pairs. With no photons, there's no outward pressure—and the star begins to collapse.

One of two things can happen next. The collapse can create even more pressure, reigniting enough oxygen to create a burst of energy. This burst is enough to toss off the outer layers of the star but not enough to create a full supernova. The cycle can repeat itself in pulses—astronomers call this case a "pulsational" pair-instability supernova—until the star loses enough mass to end its life in an ordinary supernova. A team led by the California Institute of Technology's Robert M. Quimby announced it had identified one of these and has submitted a paper for publication.

If the star is really big—and here we're talking more than 130 solar masses—the collapse happens so fast and gathers so much inertia that even fusing oxygen can't stop it. So much energy develops in such a little space that eventually the whole thing blows up, leaving no remnant behind. This is "the real deal, the big stuff," says Avishay Gal-Yam, an astronomer at the Weizmann Institute of Science in Rehovot, Israel, whose team claims in a recent paper in *Nature* to have discovered the first full-fledged pair-instability supernova (*Scientific American* is part of Nature Publishing Group).

Before the findings, most astronomers had argued that gigantic stars in nearby galaxies slough off much of their mass before dying out, precluding a pair-instability supernova. These ideas are being reconsidered, now that these biggest of explosions have announced themselves in spectacular fashion. *—Michael Moyer*

DATA POINTS

EXPLOSIVE EVIDENCE

3,767

The number of supernovae discovered since 2000, more than twice as many as had been discovered before then.

COMMENT ON THESE ARTICLES www.ScientificAmerican.com/oct2010

A cut-marked animal bone

Archaeology

The First Butchers

Hominids have been cutting their steak for much longer than anybody thought

A long time ago, by the shores of a lake in East Africa, a group of hungry foragers tucked into a primeval steak dinner. They carved the meat of cow- and goat-sized animals with sharp stone tools and smashed the bones to get at the rich marrow inside. The scene is remarkable mainly because it happened 3.4 million years ago, pushing back by 800,000 years the earliest known example of hominids using stone tools and eating meat.

The foragers in question were likely members of the primitive genus *Australopithecus*, specifically *A. afarensis,* the species to which the celebrated Lucy fossil belongs. Scientists had long believed that the australopithecines, whose teeth and jaws were adapted for eating fruit, seeds and other plant foods, were primarily vegetarian. But the new finds—cut-marked animal bones recovered from a site called Dikika, just a few kilometers from the Lucy site in Ethiopia's Afar region—suggest that "we could now be looking at an extended period of time when [hominids] were including meat in their diet and experimenting with the use of stone tools," observes lead study author Shannon P. McPherron of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany. A report describing the bones appeared in the August 12 issue of *Nature*.

What prompted this dietary switch? Some archaeologists believe ecological shifts may have led the species to seek new sources of sustenance. "It may be that behavioral adaptations allowed *A. afarensis* to adapt to these environmental perturbations without anatomical changes," surmises archaeologist David R. Braun of the University of Cape Town in South Africa.

Critics have questioned whether the marks really did come from stone tools, partly because none were found at the site. Future discoveries are likely to resolve that question. "I think we will start seeing many more people searching more intently … for this type of evidence," Braun predicts.

—Kate Wong

COURTESY OF DIKIKA RESEARCH PROJECT (*cut-marked bone*); GETTY IMAGES (*cacao pod*)

Food

Death and Chocolate

A blight is threatening the world's cocoa supply. Will genetic intervention save our dessert?

In a rare tale of technology, bioterrorism and chocolate, scientists are racing to sequence the cacao tree genome. They fear that without the genome in hand they will be unable to stop the spread of two virulent pathogens that threaten to devastate the world's cocoa crop.

Cacao trees were first domesticated more then 1,500 years ago by Mayans living in what is now Central America, but fungal diseases such as witch's broom and frosty pod have largely chased the bean out of its native habitat. The great worry is that one of these diseases will cross the Atlantic Ocean to West Africa, where 70 percent of the crop is now produced. Cacao trees in West Africa have no resistance to the pathogens, which form spores and spread via the wind, careless farmers and, in at least one case, bioterrorists. Scientists say that just a few infected pods would lead to the loss of one third of total global production.

One way to forestall such a crash is to breed plants that are resistant to infection. Scientists identify naturally resistant plants, artificially pollinate them, then test their offspring. This is a slow process, and having the cacao genome in hand would speed things up. Scientists would be able to identify the sections of DNA that confer increased resistance and select the best trees to breed. "It's expensive work," says Randy C. Ploetz, a plant pathologist at the University of Florida, "but once you have a genetic sequence, it makes that work a lot easier."

Pod squad: Scientists are racing to breed resistance in cacao trees to a deadly disease.

Scientists expect to release a first draft of the cacao genome by the end of the year; identifying the genetic sites responsible for resistance will take a few years more. In the meantime, producers in Côte d'Ivoire and Ghana have instituted strict quarantines to help protect their crops.

—Michael Moyer

QUOTABLE

"Psychopathy, like autism, and many of the clinical disorders, is a spectrum.... Many of us are narcissistic, many of us are impulsive at some level. Many of us do all sorts of things that are at least somewhat morally wrong. We're somewhere on the spectrum."

Harvard University evolutionary psychologist **Marc Hauser,** speaking at a July 2010 conference on "The New Science of Morality." Harvard later said it had found him guilty of scientific misconduct.

Scientist in the Field

Trash Is Her Treasure

A New York University anthropologist discusses why she has spent the past four years working alongside New York City's garbage men and women

How did you get interested in trash? When I was a child, my dad and I went hiking in the Adirondack Mountains, and we spent hours in a forest that seemed like we were the first human beings to ever walk in. And then we arrived at our campsite; behind the lean-to there was a dump left by hikers who had come before. I was absolutely astonished that people I assumed cared about the environment would in fact trash it. Who did they think was going to come and clean it up? And that question stayed with me.

How do you describe your job at cocktail parties? I'm an anthropologist by training and by passion, and right now I'm working on a project with the New York City Department of Sanitation that grew out of questions I had around issues of waste. When I framed [the question of] "who cleans up after us" anthropologically, I came to know the men and women whose work it is to pick up the garbage, to sweep the streets, to plow the snow. After I had been doing fieldwork for a while, I actually took the job as a sanitation worker and was trained to drive the trucks. But I realized I couldn't hold that title and my N.Y.U. job at the same time, so I became an anthropologist-in-residence, a position from which I can organize a museum and pull together an oral history project of sanitation folk.

PROFILE

NAME
Robin Nagle

TITLE
Anthropologist-in-Residence, New York City Department of Sanitation

LOCATION
New York City

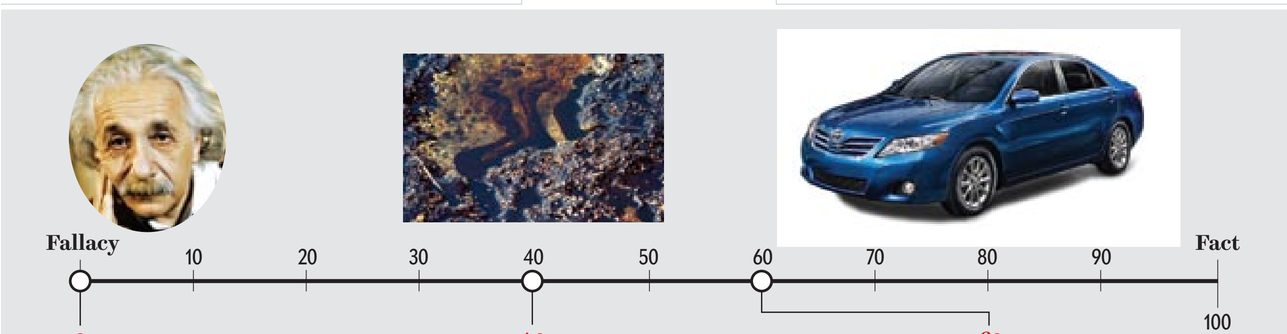
Are there other sanitation anthropologists? In many ways, archaeology rests on the study of garbage, except that the garbage is a few hundred or a few thousand years old. But there are also some archaeologists looking at contemporary household waste—Bill Rathje is one of the key founders of that particular discipline. There are other anthropologists working with sanitation workers, but I know of no one else with the title "anthropologist-in-residence."

Why have we created a global economy that generates such vast quantities of waste? That's rooted in the basic structures of capitalism, which requires perpetual renewal to continue to generate profit at the pace that is now understood to be necessary for local, regional and global economic health. It's the rhythms of our economic structures that have set up these patterns.

What are some surprising things you've learned by analyzing garbage? In affluent neighborhoods, I was profoundly impressed with how much good stuff rich people throw away.

—Nicholette Zeliadt

SCIENCE INDEX



0
Conservapedia, the online encyclopedia run by conservative lawyer Andrew Schlafly, implies that Einstein's theory of relativity is part of a liberal plot.

40
Government scientists report that three quarters of the oil that spilled into the gulf is "gone." Newer, independent evidence suggests far more remains.

60
Last year Toyota claimed that electronic problems were not to blame in reports of sudden acceleration in its cars. Preliminary U.S. government reports show that the company was right.

COURTESY OF ROBIN NAGLE (*Nagle*); GETTY IMAGES (*Einstein*); JEFF HALLER *New York Times* (*oil spill*); COURTESY OF TOYOTA (*car*)

Physics

Just How Small Is the Proton?

New findings challenge a basic theory of physics that presumably had been settled

Physicists have been scratching their heads since July, when a research team announced that the proton, the basic building block of matter, is 4 percent smaller than previously thought. The finding, published in *Nature*, clashes with theoretical predictions based on quantum electrodynamics, or QED, the fundamental theory of the electromagnetic force that had passed the most stringent tests in physics.

Randolf Pohl of the Max Planck Institute for Quantum Optics in Garching, Germany, and his collaborators used a laser to probe exotic, man-made hydrogen atoms in which elementary particles known as muons replaced the usual electrons orbiting the single-proton nuclei. Laser energy made the atoms fluoresce at characteristic x-ray wavelengths. Those wavelengths reflected a number of subtle effects, including the little known fact that an orbiting particle—be it a muon or an electron—often flies straight through the proton. That is possible because protons are composed of smaller elementary particles (mainly three quarks), and most of the space inside a proton is actually empty.

By calculating the effects of the proton's radius on such fly-through trajectories, the researchers were able to estimate the proton's radius to be 0.84184 femtometer (one femtometer is one quadrillionth of a meter). This figure is smaller than all previous measurements made, which ranged between 0.8768 and 0.897 femtometer. (Either way, the proton is a lot smaller than even a hydrogen atom: if the atom were the size of a football field, the proton would be the size of an ant.)

In dealing with such tiny quantities, the possibility for error always exists. Yet after 12 years of painstaking efforts ("You need to be stubborn," Pohl says), the team members are confident that some unforeseen subtlety in their apparatus hasn't thrown off their measurement. Theorists have also double-checked the calculations involved in interpreting the muons' behavior and predicting the size of the proton, which are relatively straightforward, says Ulrich D. Jentschura, a theorist at the Missouri University of Science and Technology in Rolla.

Some physicists have suggested that the interaction between the muons and the proton could be complicated by unforeseen pairs of particles and their antiparticles, which might appear briefly from the vacuum in and around the nucleus. The most likely candidates, Jentschura says, are electron-antielectron pairs, which are not supposed to show up in the everyday physics of atoms, at least not according to the standard theory. "It could be the first indication that something is wrong with our picture" of QED, says Krzysztof Pachucki, a theorist at the University of Warsaw in Poland. The theory might need some tweaking, but likely not a complete overhaul, he says. Whatever the answer, physicists will most likely have plenty to keep scratching their heads about for years to come. *—Davide Castelvecchi*

DATA POINTS

A MATTER OF DEGREES
(Measured in meters)

0.00001
Size of a human cell

0.0000000001
Size of a hydrogen atom

0.00000000000000084184
Size of a proton, according to the newest measurements

Technology

The Power of Sniff

A new device lets the disabled move and communicate with their noses

The key to restoring movement and communication for the severely disabled may lie on the roofs of our mouths. Researchers have invented a device that allows the paralyzed to write, surf the Web and steer an electric wheelchair—all by sniffing. Initial tests, described recently in *Proceedings of the National Academy of Sciences USA*, suggest that patients with severe paralysis may soon have a new way of doing everyday tasks.

Sniffing is controlled in part by cranial nerves in the soft palate, the tissue lining the back of the roof of the mouth. Because these nerves emerge directly from the brain, as opposed to the spinal cord, they remain intact for many severely paralyzed people. They also control the ability to blink, sip and puff.

The sniff controller, which was developed by Anton Plotkin and his colleagues at the Weizmann Institute of Science in Rehovot, Israel, uses a small plastic tube that fits into the nose. It measures pressure, translating variations in intensity and frequency of sniffing in and out into commands for a computer or wheelchair.

In the study, the researchers tested the controller on 15 disabled patients; 13 used the technology to write messages or surf the Web and one to maneuver his wheelchair. (The 15th volunteer made no progress.) Further testing is required, but Plotkin is optimistic: "We figured out that sniffing can control just about anything." *—Ferris Jabr*

The nose knows: Plotkin and his sniff controller, which operates laptops and wheelchairs.

COURTESY OF WEIZMANN INSTITUTE OF SCIENCE

Medicine

A View to a Kill

A new imaging technique shows how diseases work in real time

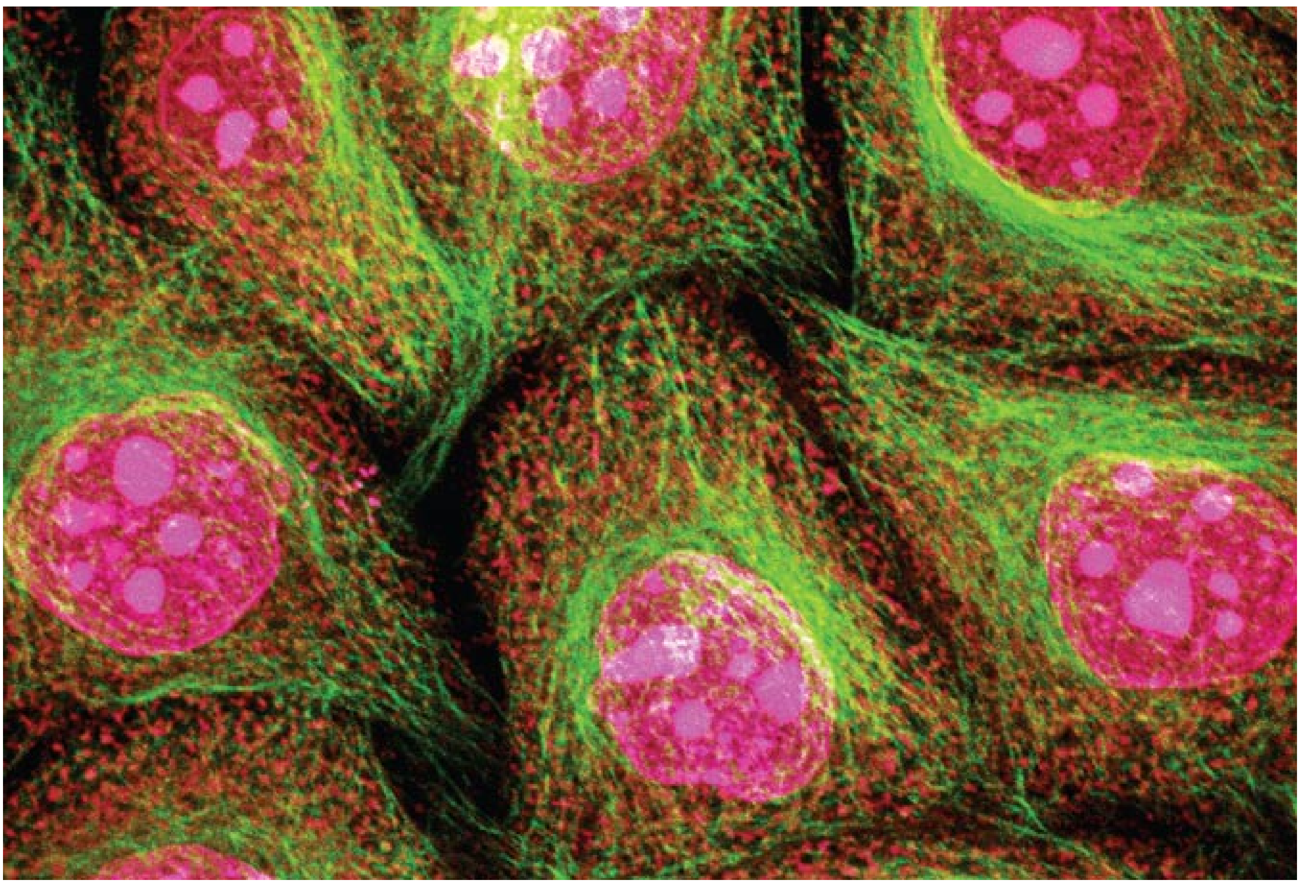
The most powerful machines are also the most destructive, a rule that applies even in the confines of the body's cells. Mitochondria, the cell's energy powerhouses, can fuel the development of many chronic and poorly understood conditions, including cancer, heart disease, and neurodegenerative disorders such as Parkinson's and Alzheimer's. The disease process starts when environmental factors such as polluted drinking water or cigarette smoke perturb mitochondria, causing cellular levels of high-energy molecules called reactive oxygen species to spike.

Until now it has been unclear exactly how this destructive cascade unfolds. But researchers have developed an imaging technique that shows, in real time, what happens when things start going awry—a tool that could help doctors diagnose mitochondrial injuries before they have the chance to do serious cellular damage.

Scientists have long assumed that wounded mitochondria release reactive oxygen molecules, which then damage DNA and proteins, increasing disease risk. But some of the environmental chemicals that harm mitochondria produce these dangerous molecules themselves, prompting a "cause-and-effect question," explains James M. Samet, a toxicologist at the National Health and Environmental Effects Research Laboratory in Chapel Hill, N.C., who has co-authored a study on the new technique in the journal *Environmental Health Perspectives*. Are these reactive molecules just injury by-products, or do they cause mitochondrial damage instead? "The only way you're going to make heads or tails of this question is to actually observe, in real time, in living cells, these events as they unfold," Samet says.

To do this, the researchers coaxed three fluorescent molecules into the mitochondria of living human skin cells. One lit up in the presence of hydrogen peroxide, a prominent reactive oxygen species, whereas the other two acted as mitochondrial injury sensors. Next they exposed the cells to a mitochondrial toxicant. The damage sensors lit up first, with the hydrogen peroxide marker following moments later, suggesting that the reactive oxygen molecules are indeed a sign, and not a cause, of injury.

Although more validation is necessary, Samet is confident that the development could help researchers understand the genesis of many chronic diseases. *—Melinda Wenner Moyer*



GOPAL MURTI *Photo Researchers, Inc.*

Mighty mitochondria: Researchers have developed a tool that allows them to observe the cell's energy powerhouses, mitochondria (*in red*), as a disease unfolds.

WHAT'S AHEAD?

Self-Cleaning Solar Panels

The best places to collect solar energy are also some of the dustiest on Earth. When dirt settles on a solar panel, it blocks sunlight, preventing the panel from efficiently converting rays into electricity.

A solution, according to new research by Malay Mazumder, a research professor in Boston University's department of electrical and computer engineering, is to coat solar cells with an electrically charged material that repels the dust particles. The technology could also be applied to the windshields of helicopters and other vehicles, as well as equipment used on the moon and Mars.

—Larry Greenemeier

Military

Getting GPS out of a Jam

How tiny waves of matter may help missiles stay on track

GPS, the Global Positioning System we rely on for guiding nuclear missiles and steering tourists to Mount Rushmore, has become a ripe target for enemy attack. In response, U.S. scientists are developing new ways to circumvent blocked GPS signals using matter waves to measure acceleration.

GPS is vulnerable because the radio signals that satellites broadcast to receivers, such as those in smart phones and in cars, are so weak that even low-power jammers can easily block them. (GPS devices use the signals from several satellites to triangulate their position.) During the past decade, China and other countries have put satellites for their own regional navigation systems into orbit that work on different frequencies, which means that on a battlefield they could block U.S. signals without disrupting their own.

To get around this potential risk, U.S. scientists are developing gadgets that can track an object's position in the event GPS signals are cut off. These inertial measurement units, or IMUs, determine a target's location by measuring changes in acceleration since the last GPS reading. Until now such devices, based on a variety of technologies from mechanical to laser-based, have often been bulky and prone to error after prolonged use. By taking advantage of the quantum-mechanical properties of matter, however, engineers have come up with gadgets that could prove 1,000 times more accurate.

These "cold atom" devices use lasers and magnets to confine clouds of atoms into a very narrow range of energies, explains Werner J. A. Dahm, the U.S. Air Force's chief scientist. (Such constraints make them "cold" in a quantum-mechanical sense, not in temperature.) Under these conditions, scientists can detect matter behaving like a wave. The devices split these matter waves in two and send each part in opposite directions before bringing them back together. If the device moves while the waves are split apart, one wave will experience acceleration slightly before its counterpart. The laser detects this change when the waves recombine. Because the waves have very small wavelengths—billionths of a meter in size—scientists can use them for ultraprecise measurements of acceleration. The gadgets might be ready for wide-scale use within a decade.

—Charles Q. Choi

Technology

There's Wisdom in Those Tweets

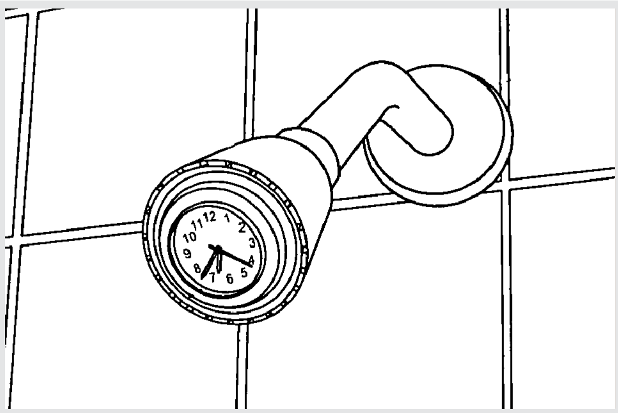
Researchers mine Twitter and find gold

Critics have derided the 140-character messages posted daily on Twitter as trivialities. Yet to researchers, the popular social media site presents a rich trove of data. Barbara Poblete and her colleagues at Yahoo Research in Santiago analyzed tweets in the wake of February's Chilean earthquake to learn how rumors propagate online. They found that people used Twitter to sort truth from falsehoods. Poblete's group saw that 62 percent of tweets with earthquake-linked keywords from users in the Santiago time zone questioned or denied rumors that later turned out to be false. By comparison, when it came to confirmed truths, just 2 percent of tweets questioned them, and 0.3 percent were denials. Other researchers have used Twitter to track mood changes across the U.S. Alan Mislove, a computer scientist at Northeastern University, and Sune Lehmann, a Harvard University physicist, analyzed tweets that used words psychologists rated for emotional heft, such as "triumphant" and "suicide." Their preliminary findings revealed that early mornings, late evenings and weekends rated the highest for happiness and that, unsurprisingly, the West Coast was happier than the East Coast.

The group now hopes to use Twitter to track changes in political climate. "Twitter is designed to be open, so we can look at content without violating anyone's privacy," Lehmann says. In April, Twitter announced it would donate its public tweet history to the Library of Congress. Researchers, at least, will be in a good mood about that.

—Charles Q. Choi

PATENT WATCH



Greg Foutz used to waste *a lot of time—and water—in the morning. "The best-quality thought time you have is when you're taking a shower," he says. Trouble is, his showers were so lengthy that he was frequently late for work making pizzas at a local parlor in Stockton, Calif. One day a brainstorm hit: with his wife and a friend, Foutz, 45, designed a waterproof clock to fit inside a showerhead. The clock also functions as a timer and conscience, alerting users at regular intervals to how much time they've spent washing up. The idea for his "Timepiece Shower Head" earned the group a patent this past July.*

Showering is one of the largest contributors to a household's overall water use, accounting for up to 25 percent of energy costs. Worse than that, prolonged bathing means "someone in the family ends up with a cold shower and gets mad," Foutz says. His goal is to manufacture the device cheaply enough so that water municipalities could distribute it free of charge, just as they do now with low-flow showerheads.

—Anna Kuchment

NICK KOUDIS *Getty Images*; PATENT DRAWING COURTESY OF GREG FOUTZ

High life: Squid fins may act like wings, scientists say.

Behavior

Flight of the Squid

New photos offer the best evidence yet of mollusk aeronautics

Marine biologist Silvia Maciá was boating on the north coast of Jamaica in the summer of 2001 when she noticed something soar out of the sea. At first she thought it was a fish. After tracing the creature's graceful arc for a few seconds, Maciá realized it was a squid—and it was flying.

The sighting led Maciá, who teaches at Barry University in Florida, to co-author one of the first studies on squid aeronautics in 2004. She and her colleagues noted that squid as small as 20 centimeters could launch themselves as high as two meters above the water and propel themselves, actively flapping their fins and spiraling their tentacles, for a distance as great as 10 meters. The paper collected sightings of at least six distinct squid species squirting themselves as high as three meters over the waves using jet propulsion, the process of taking in and forcing out liquid to generate thrust. Sometimes the squid flew solo, sometimes in packs, sometimes with enough force to match the speed of boats.

Mounting photographic and anecdotal evidence is helping scientists puzzle out the mechanics of squid flight. Ron O'Dor, a senior scientist at the Census of Marine Life, is analyzing images taken last year off the coast of Brazil that may provide the best-ever photographic documentation of airborne squid. "When you look at some of the pictures, it seems they are more or less using their fins as wings," says O'Dor, who is hoping to calculate squid velocity, among other details, from the images. *—Ferris Jabr*

DATA POINTS

JET SET

20

Length, in centimeters, of Maciá's squid

10

The distance, in meters, that squid can fly (about 50 times their body length)

3

The height, in meters, at which squid can fly above the water

Do the Math

When Small Numbers Lead to Big Errors

A statistician weighs in on the pitfalls of estimating the sizes of small groups

As the U.S. military embarks on its review of Don't Ask, Don't Tell, to be delivered in a final report later this year, the question arises: How many service members are affected by the policy? To help answer that question, the Pentagon this past summer surveyed its troops, asking them if they served or had ever served with someone they believe to be gay. Leaving aside an obvious problem with the survey—that it is based on pure speculation—it also raises a common statistical challenge: asymmetry in population sizes. Because the vast majority of service members are heterosexual, many more straights will be misclassified as gays than vice versa.

This is a general problem in survey research. For example, Harvard University researcher David Hemenway has shown how some well-publicized studies have overestimated the number of guns used in the U.S. for self-defense by 10 times. Even if only 1 percent of respondents answer the survey incorrectly, the error is large compared with the proportion of the general population that owns guns for self-defense, which reasonable studies show to be about 0.1 percent. In other words, the misclassification rate far exceeds the actual population size. To get around this problem, we would be wiser to trust surveys of crime victims, which restrict the gun use question to a smaller pool of subjects.

As to our original question, a reasonable (though still imperfect) way to figure out what percentage of military service members are gay is by combining two estimates: the percentage of gays in the general population (easy enough to estimate from national surveys) and an estimate of the percentage of individuals in same-sex unmarried partner couples who report ever having served in the military (known as a probability). By extrapolating from the general population to service members, you are restricting your analysis to same-sex unmarried couples and thus narrowing the pool of potential false positives. Gary J. Gates of the University of California, Los Angeles, estimates using this method that 1.5 percent of men and 6.2 percent of women in the military are gay or bisexual. *—Andrew Gelman*

Gelman is a professor of statistics and political science at Columbia University. He blogs at www.stat.columbia.edu/~gelman/blog

COURTESY OF BOB HULSE

WHAT IS IT?

Field of dreams: *More than a decade ago the town of Inakadate in northern Japan began looking for ways to bring in more tourists. But this rural community had little to offer: no sea, no major landmarks, just rice and apple trees. Then, a local clerk had an idea: Why not turn Inakadate's plentiful rice paddies into canvases? Since 1993 villagers have planted multiple varieties of rice in patterns that have evoked nearby mountains and the Mona Lisa. This past summer's chef d'oeuvre* (pictured at left) *featured a samurai battling a warrior monk. Villagers sketched the image on computers before planting and used genetically engineered rice to add more colors. Visitors now throng Inakadate every year to view its latest "crop."* —Anna Kuchment

Neuroscience

Craving a Cure

Researchers turn to virtual worlds for real-world insights into addiction

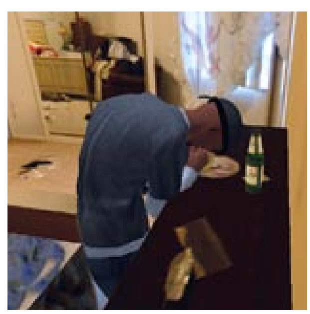
Virtual worlds offer millions of online visitors the chance to ride a dragon or build a fake real estate empire. Addiction researchers have discovered that these communities can also produce something very real—drug cravings—which may help scientists develop and test new treatments for substance abuse.

Researchers have struggled for decades with the problem of reproducing so-called environmental cues within the confines of a sterile lab environment. These reminders—a rolled-up dollar bill, the smell of cigarette smoke—make users crave their drug of choice. The investigators stoke powerful cravings in their subjects to better understand the physiology of addiction and to reliably test whether a new drug or behavioral therapy can prevent relapse.

Chris Culbertson, a doctoral student in neuroscience at the University of California, Los Angeles, had read reports of alcoholics and smokers developing cravings while visiting virtual worlds devised by addiction researchers. He decided to use one of the largest online communities, Second Life, to study another intractable problem: addiction to the psychostimulant methamphetamine. Culbertson created a virtual meth house, a place where addicts gather, and invited 17 meth users to U.C.L.A. to test it out. To determine their levels of craving, Culbertson had the addicts fill out questionnaires and measured their heart rates as they navigated via computer through the meth house on Second Life. A recent study in *Pharmacology, Biochemistry and Behavior* showed that Culbertson's virtual-reality meth house bested other imagery in eliciting cravings, including a video of actors pretending to use the drug.

For now, Culbertson says, his virtual meth house is off-limits to the general public: "It would throw a monkey wrench into the whole thing if someone showed up in a dragon suit while we were doing an experiment." *—Gary Stix*

Virtual high: Culbertson's meth house on Second Life portrayed graffiti-covered walls and pipe-strewn floors.



SHIHO FUKADA *Redux Pictures* (top); COURTESY OF LINDEN RESEARCH, INC. (bottom)

Christine Gorman is an award-winning science journalist who has covered health and medical topics for more than 20 years.

Closing the Health Gap

Expanding primary care may be the best way to resolve chronic disparities

HORACIO SALINAS *Trunk Archive*

The U.S. outspends all other industrial countries on health care, and yet we do not enjoy better health. Quite the opposite: an American baby born in 2006 can expect to live to 78—two years less than a baby born across the Canadian border. Out of the 30 major industrial countries, the U.S. ranks 28th in infant mortality. A large part of the gap in infant mortality can be traced to high infant death rates in certain populations—particularly African-Americans, who make up about 13 percent of the total population. In 2005 infant mortality for non-Hispanic blacks in the U.S. ran to 13.6 deaths per 1,000 live births compared with 5.76 deaths per 1,000 live births for non-Hispanic whites. The root causes of such disparities—which include differences in education, environment, prejudice and socioeconomic status—are notoriously intractable.

An easier fix may be under our noses: primary care. The idea is to have a clinician who knows your health history, will continue caring for you over the long term, and can recommend specialists and coordinate your treatment if you need to see them. Primary care can handle the health problems that most people have most of the time.

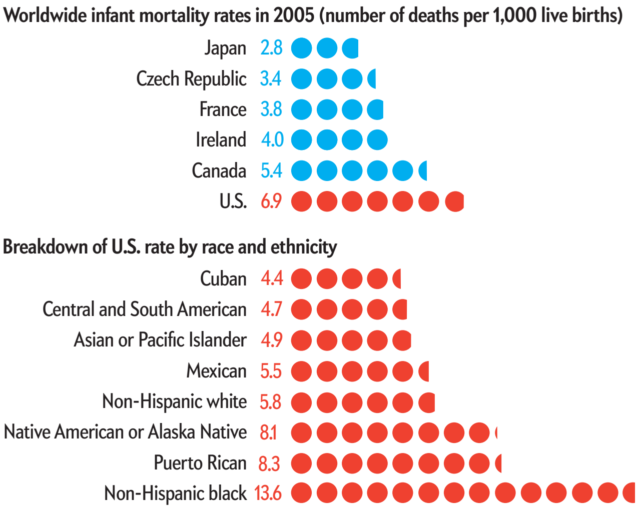
Research confirms the value of such care for the general population. The greatest benefits come to poor and socially disadvantaged groups, but they also extend to the well-to-do. Indeed, the need to strengthen primary care in the U.S.—making it more available—is one of the major tenets of the health reform laws that were enacted this past spring. A decline in availability in recent decades is a big reason why U.S. health has lagged behind that of so many other wealthy nations.

Primary care used to be the only game in town. In the late 19th century a family would rely on the same person (not always a doctor) to deliver babies, monitor and treat coughs and fevers, salve pain, comfort the dying, and assuage the grief of loss. Only the poor and the desperate went to hospitals. That changed in the 20th century, as advances in medical technology and in the education of physicians and nurses made hospitals safer places to be.

After World War II, Americans began associating medical progress with specialization. (In Europe, by contrast, the rebuilding effort led many nations to focus on general care—an emphasis that continues today.) The phrase "primary care" was invented in the U.S. during the 1960s in an effort by pediatricians and general practice physicians to resist the pull toward specialists. That effort failed; now only one third of U.S. physicians are primary care doctors—compared with about half in other industrial countries.

Primary care increases life span and decreases disease burden in part because it helps to prevent small problems, such as strep throat, from becoming big ones, such as a life-threatening infection of the heart. Having a regular clinician of that kind makes you a better patient because you trust the advice you receive and so are more likely to follow it; it also gives you access to someone who attends to the whole person, not just one body part. In addition, having someone to coordinate your care can be critical if you have multiple providers—as, for example, when you leave the hospital. (This coordination task is very different from the managed care trend of the 1990s that, under the guise of care coordination, turned many providers of pri-

Room for improvement: **The fraction of infants who die in their first year of life in the U.S. is higher than for many other industrial nations. Non-Hispanic blacks here fare the worst; Cubans, the best. Studies suggest that better access to primary care for moms and infants could save many lives.**



SOURCES: OECD (*worldwide data*); CDC/NCHS (*U.S. data*)

mary care into gatekeepers who, in fact, mostly denied care.)

The many benefits of primary care show up in a range of research. Studies in the 1990s showed that those parts of the U.S. that had more primary care physicians for a given population had lower mortality rates for cancer, heart disease or stroke—three major causes of premature death—even after controlling for certain lifestyle factors (seat belt use, smoking rates) and demographic attributes (proportion of elderly people). By the 2000s researchers had linked access to such clinicians to lower rates of specific conditions, such as ruptured appendix (which requires emergency surgery) and low birth weight (which causes health problems in many infants).

A study of more than 9,500 people with either high blood pressure or high cholesterol, which was published in the *American Heart Journal* this past July, sheds a little more light on why this relationship works so well. It found that having a usual source of care—a primary care provider or clinic—significantly decreased a person's risk of going untreated for high blood pressure or high cholesterol whether or not the individual had insurance. This finding suggests that health reform has to do more than provide affordable health coverage for all who need it. It must also ensure access to a primary care provider.

Primary care has delivered some of its greatest gains in the African-American population. One study from 2005 showed that access reduced deaths in that group four times more than in whites—even after controlling for education and income. Part of the difference probably has to do with the slightly higher rates of hypertension among African-Americans. Treating high blood pressure is a proved way of preventing heart attack, stroke and kidney failure. Part of the difference also probably has to do with regular screening for cancers—such as colon and cervical—that are readily treatable if caught early. "In the cancer realm, a lot of the difference [between racial/ethnic groups] is lack of insurance and lack of a usual source of medical care," says Ann S. O'Malley, a primary care physician who is a senior researcher at the Center for Studying Health System Change in Washington, D.C. Both lines of evidence strongly suggest that making primary care more broadly available could go a long way toward decreasing health disparities among whites, blacks and other racial/ethnic groups.

Among wealthier people, a big, perhaps surprising benefit of primary care is that it keeps patients from going too often to a specialist, where they can be overtreated or misdiagnosed. "Most people do not realize the dangers of too much specialty care," says Barbara Starfield, a health systems researcher at the Johns Hopkins Bloomberg School of Public Health. She points to research showing that primary care physicians are better all-around diagnosticians than specialists and achieve better overall health outcomes for their patients. Unnecessary treatment turns out to be a bigger problem than most people in the medical field—including specialists—care to admit. Every test, every diagnostic procedure, every surgery has its own complication rates. For example, undergoing cardiac catheterization to see if the arteries in your heart are blocked slightly increases the risk of fatal internal bleeding—which is why you have to lie so still after the procedure.

Primary care is not a panacea, of course. Sometimes you really do need a brain surgeon to save your life. But more and more high-performing health care networks are noticing the benefits and reorganizing care delivery, as a report by the Josiah Macy Foundation concluded in the spring. After North Carolina restructured some of its pediatric Medicaid programs in the late 1990s to emphasize primary care—providing more evening and weekend appointments and paying for more follow-up visits—hospitalizations for asthma dropped by 40 percent. In 2007 the Group Health Cooperative in Washington State determined that patient satisfaction was up, visits to the emergency room were down, and costs were lowered just one year after it started providing more primary care services.

Patient satisfaction was up, visits to the emergency room were down, and costs were lowered just one year after [the Group Health Cooperative in Washington State] started providing more primary care services.

Of course, for the nation to reap the advantages of primary care, it must have enough practitioners. The health reform laws of 2010 increased the payment for some primary care services by 10 percent, but it did not go far enough to address the growing shortage of providers, Starfield and O'Malley say. Physicians are retiring from or leaving primary care in droves because it does not pay as well as specialty care. Advanced practice nurses and other health care workers who could meet more of the demand are hamstrung by outdated state regulations. "I am a primary care–trained physician, and I can't find a primary care provider for myself," O'Malley says. Access is likely to get tighter. The Congressional Budget Office estimates that an additional 32 million previously uninsured people will have health coverage as a result of the health laws of 2010. If health care reform is going to succeed, they—like the rest of us—will need to find a primary care provider. SA

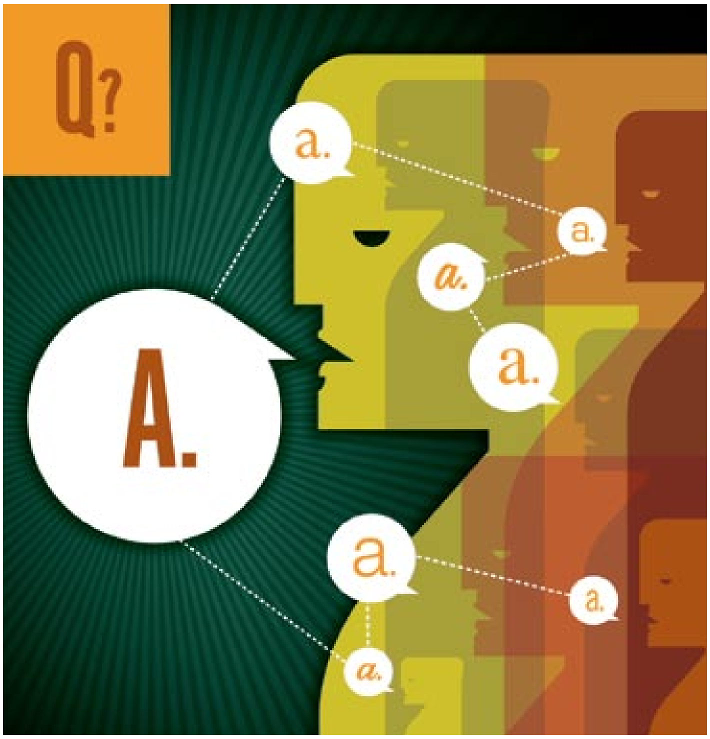
COMMENT ON THIS ARTICLE www.ScientificAmerican.com/oct2010

Graphic by Jen Christiansen

David Pogue is the personal-technology columnist for the *New York Times* and an Emmy Award–winning correspondent for *CBS News*.

Question Time

To find the best answers, digital services are turning to actual humans



The Internet is an overwhelmingly powerful source of information, but the technology for harnessing that information, for getting it filtered and delivered how and when we want it, is still in its infancy. If you don't believe it, see what kind of useful information you get when you Google "What kind of harmonica should I get for my 10-year-old?"

Recently, though, a flock of new services have cropped up to deliver highly targeted answers by passing your queries on to a sea of strangers. Call it informational crowdsourcing.

Some are simple Web sites where you can post a question for all to see, then wait for random Web users to reply. That's how Yahoo Answers and Answerbag.com work. "What's a good starter beer?" "Do you believe spanking is a good form of discipline?" "Is it cheating if I have chat-room sex?"

It's a rather crude form of crowdsourcing. You have no control over who answers your questions, it's all anonymous, and the answers may take days or weeks to arrive. Still, it's fascinating to see what the world thinks.

If you want your answers faster, you can try a phone-based service like ChaCha. Call 800-2CHACHA and speak your question. In about a minute, a text message appears on your phone, usually with a clear, succinct answer.

"What's that word that means when the sun, moon and earth are all in a straight line?" you might ask. And the text message comes in: "The straight-line configuration of 3 celestial bodies (as the sun, moon and earth during a solar or lunar eclipse) is a syzygy."

Actual humans are on the other end—your personal army of research assistants. The members of this freelance army are paid 20 cents per answer, and they use Google and whatever other research tools they need. A one-line ad at the bottom of the text message pays for the whole thing.

But while ChaCha is a useful way to get hard facts ("What's the last flight out of Chicago?"), it's no good for soliciting informed opinions ("How should I punish my teenager?"). That's where better targeting comes in. If you've managed to cultivate a circle of like-minded followers on Twitter, for example, you can get instantaneous answers to very technical or very specific questions. You don't need a lot of followers to get fast, expert answers, as long as they are mostly in your industry or your field.

The ultimate instant-answer service, though, may be Aardvark. It combines the "who you know" aspects of Twitter with the real-time features of ChaCha and the mass-audience potential of Yahoo Answers and Answerbag. It's good for getting both facts and opinion.

To use Aardvark, you sign up at vark.com, then you submit a question by e-mail, instant message, Twitter or iPhone app.

Behind the scenes, the service figures out who else in your extended social circle might be able to answer your question. It analyzes the profiles and interests of all your Facebook friends, and, if necessary, it expands the quest to *their* friends and even *their* friends. It pings only other Aardvark users and limits your question to a few people at a time, so there is no risk of spamming your entire contact list every time you want a hotel recommendation.

But that's all invisible to you; all you know is that you get two or three expert, thoughtful responses within seconds. Aardvark is so efficient at delivering targeted information that the company attracted the attention of Google, which then bought it in February for $50 million. Fortunately, like all the services described here, it remains free.

In the end, it's not technology that lends magic to these services and keeps them free—it's psychology. People like to help out, to feel needed, to be asked for their opinions. In other words, Aardvark, Twitter and the other free-answer services may be ingenious new channels—but it's human nature that makes them tick. SA

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/oct2010

Illustration by Tom Whalen

Jonathan K. Pritchard is professor of human genetics at the University of Chicago and a Howard Hughes Medical Institute investigator. He studies genetic variation within and between human populations and the processes that led to this variation.

EVOLUTION

How We Are Evolving

New analyses suggest that recent human evolution has followed a different course than biologists would have expected

By Jonathan K. Pritchard

IN BRIEF

As early *Homo sapiens* spread out from Africa starting around 60,000 years ago, they encountered environmental challenges that they could not overcome with prehistoric technology.

Many scientists thus expected that surveys of our genomes would reveal considerable evidence of novel genetic mutations that have recently spread quickly throughout different populations by natural selection—that is, because those who carry the mutations have greater numbers of healthy babies than those who do not.

But it turns out that although the genome contains some examples of very strong, rapid natural selection, most of the detectable natural selection appears to have occurred at a far slower pace than researchers had envisioned.

Illustrations by Owen Gildersleeve

Thousands of years ago humans moved for the first time into the Tibetan plateau, a vast expanse of steppelands that towers some 14,000 feet above sea level. Although these trailblazers would have had the benefit of entering a new ecosystem free of competition with other people, the low oxygen levels at that altitude would have placed severe stresses on the body, resulting in chronic altitude sickness and high infant mortality. Earlier this year a flurry of genetic studies identified a gene variant that is common in Tibetans but rare in other populations. This variant, which adjusts red blood cell production in Tibetans, helps to explain how Tibetans adapted to those harsh conditions. The discovery, which made headlines around the world, provided a dramatic example of how humans have undergone rapid biological adaptation to new environmental circumstances in the recent past. One study estimated that the beneficial variant spread to high frequency within the past 3,000 years—a mere instant in evolutionary terms.

The Tibet findings seemed to bolster the notion that our species has undergone considerable biological adaptation of this sort since it first left Africa perhaps 60,000 years ago (estimates range from 50,000 to 100,000 years ago). The transition to high altitude is just one of many environmental challenges *Homo sapiens* encountered as it migrated from the hot grasslands and shrublands of East Africa to frigid tundras, steamy rain forests and sunbaked deserts—practically every terrestrial ecosystem and climate zone on the planet. To be sure, much of human adaptation was technological—to combat the cold, for instance, we made clothing. But prehistoric technology alone could not have been enough to overcome thin mountain air, the ravages of infectious disease and other environmental obstacles. In these circumstances, adaptation would have to occur by genetic evolution rather than through technological solutions. It was reasonable to expect, then, that surveys of our genomes would reveal considerable evidence of novel genetic mutations that have spread recently throughout different populations by natural selection—that is, because those who carry the mutations have more healthy babies who survive to reproduce than those who do not.

The genome actually contains few examples of very strong, rapid natural selection. Instead most of the visible natural selection appears to have occurred over tens of thousands of years.

Six years ago my colleagues and I set out to look for the imprints of these profound environmental challenges on the human genome. We wanted to figure out how humans have evolved since our predecessors set out on their relatively recent global journey. To what extent do populations in disparate parts of the world differ genetically because natural selection recently adapted them to different environmental pressures, as in the case of the Tibetans? What proportion of these genetic differences stems instead from other influences? Thanks to advances in technologies for studying genetic variation, we were able to begin to address these questions.

The work is still under way, but the preliminary findings have surprised us. It turns out that the genome actually contains few examples of very strong, rapid natural selection. Instead most of the natural selection visible in the genome appears to have occurred over tens of thousands of years. What seems to have happened in many cases is that a beneficial mutation spread through a population long ago in response to a local environmental pressure and then was carried into faraway locales as the population expanded into new territories. For example, some gene variants involved in determining light skin color, an adaptation to reduced sunlight, are distributed according to ancient migration routes, rather than just latitude. That these ancient selection signals have persisted over millennia without new environmental pressures overwriting them indicates that natural selection often operates at a far more leisurely pace than scientists had envisioned. The rapid evolution of a major gene in the Tibetans, it appears, is not typical.

As an evolutionary biologist, I am often asked whether humans are still evolving today. We certainly are. But the answer to the question of how we are changing is far more complicated. Our data suggest that the classic natural selection scenario, in which a single beneficial mutation spreads like wildfire through a population, has actually occurred relatively rarely in humans in the past 60,000 years. Rather this mechanism of evolutionary change usually seems to require consistent environmental pressures over tens of thousands of years—an uncommon situation once our ancestors started globe-trotting and the pace of technological innovation began accelerating.

Already these findings are helping to refine our understanding not only of recent human evolution but also of what our collective future might hold. For a number of the challenges currently facing our species—global climate change and many infectious diseases, for example—natural selection probably occurs too slowly to help us much. Instead we are going to have to rely on culture and technology.

FINDING THE FOOTPRINTS

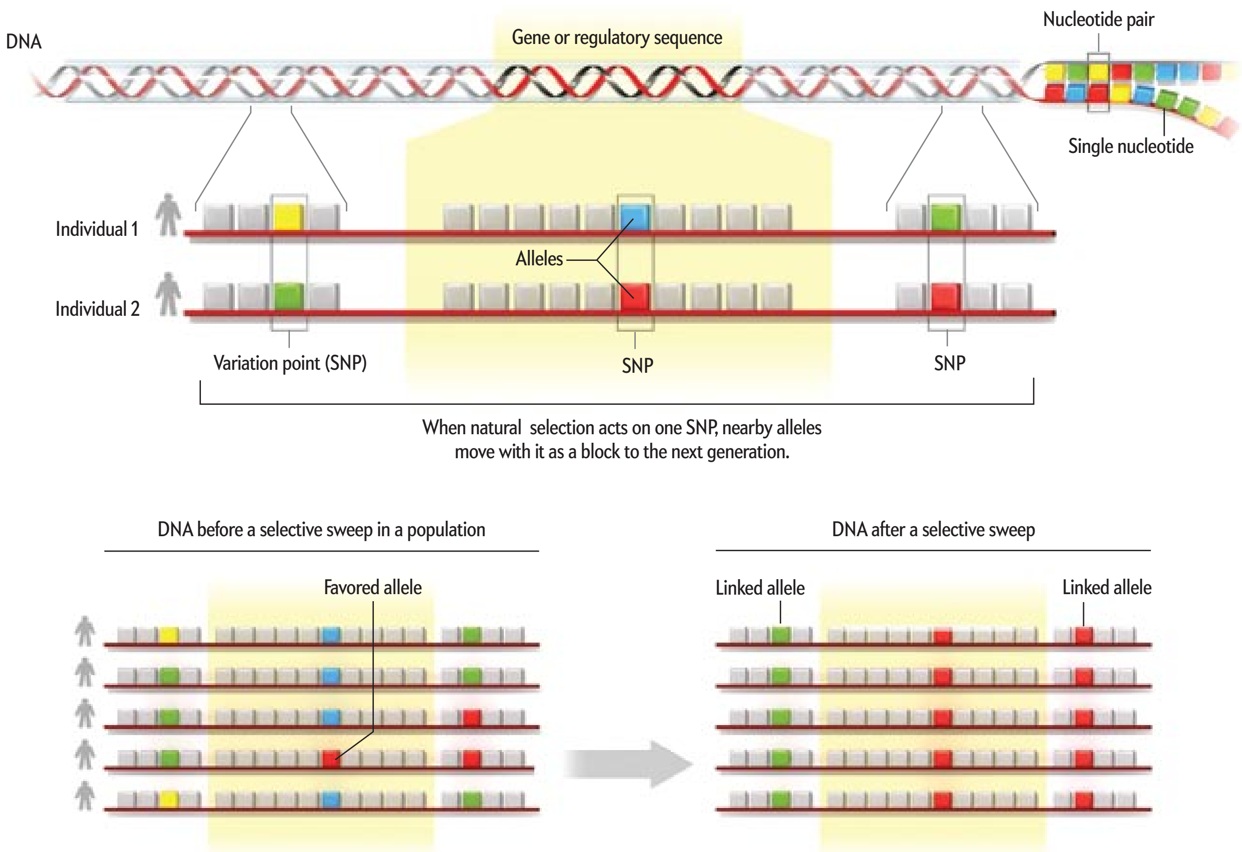
Just 10 years ago it was extremely difficult for scientists to trace our species' genetic responses to our environment; the needed tools just did not exist. All that changed with the completion of the human genome sequence and the subsequent cataloguing of genetic variation. To understand exactly what we did, it helps to know a bit about how DNA is structured and how small changes can affect its function. The human genome sequence consists of about three billion pairs of DNA nucleotides, or "letters," that serve as an instruction manual for how to assemble a human [*see box on next page*]. The manual is now known to contain a parts list of about 20,000 genes—strings of DNA letters that spell out the information required to build proteins. (Proteins, which include enzymes, do much of the work in cells.) About 2 percent of the human genome encodes proteins, and a roughly similar amount seems to be involved in gene regulation. Most of the rest of the genome has no known role.

Overall the genomes of any two people are extremely similar, differing in only about one out of every 1,000 nucleotide pairs. Sites where one nucleotide pair substitutes for another are referred to as single-nucleotide polymorphisms, or SNPs (pronounced "snips"), and the alternative versions of the DNA at

READING THE GENOME

Selection Signal

Scientists can infer that natural selection has acted on a region of DNA if they observe a lack of variability in that region. The genomes of any two people differ at only approximately one out of every 1,000 pairs of DNA nucleotides, or "letters." These points of difference are known as single-nucleotide polymorphisms (SNPs), and the alternative versions of nucleotides at each SNP are called alleles. When a particular allele ends up improving reproductive success, it ultimately spreads through a population, or is "selected." At the same time, nearby alleles travel along with the favored one and thus become more common in the population as well. The resulting reduction of SNP variation in this part of the genome in a population is termed a selective sweep.



each SNP are called alleles. Because most of the genome does not encode proteins or regulate genes, most SNPs probably have no measurable effect on the individual. But if a SNP occurs in a region of the genome that does have a coding or regulating function, it may affect the structure or function of a protein or where and how much of the protein is made. In this way, SNPs can conceivably modify almost any trait, be it height, eye color, ability to digest milk, or susceptibility to diseases such as diabetes, schizophrenia, malaria and HIV.

When natural selection strongly favors a particular allele, it becomes more common in the population with each generation, while the disfavored allele becomes less common. Eventually, if the environment remains stable, the beneficial allele will spread until everyone in the population carries it, at which point it has become fixed in that group. This process typically takes many generations. If a person with two copies of the beneficial allele produces 10 percent more children and someone with one copy produces 5 percent more, on average, than someone without the beneficial allele, then it will take that allele about 200 generations, or roughly 5,000 years, to increase in frequency from 1 percent of the population to 99 percent of it. In theory, a helpful allele could become fixed in as little as a few hundred years if it conferred an extraordinarily large advantage. Conversely, a less advantageous allele could take many thousands of years to spread.

It would be great if in our efforts to understand recent human evolution, we could obtain DNA samples from ancient remains and actually track the changes of favored alleles over time. But DNA usually degrades quickly in ancient samples, thereby hindering this approach. Thus, my research group and a number of others around the world have developed methods of examining genetic variation in modern-day humans for signs of natural selection that has happened in the past.

One such tactic is to comb DNA data from many different people for stretches that show few differences in SNP alleles within a population. When a new beneficial mutation propagates rapidly

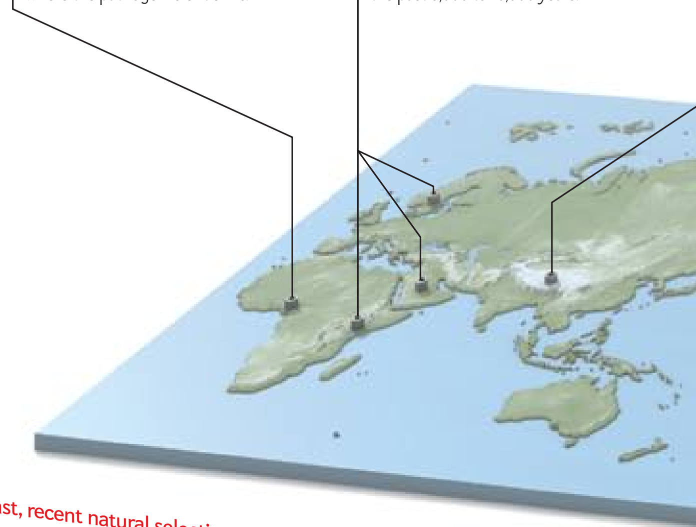
Illustration by Emily Cooper

Surprising Findings from Population Studies

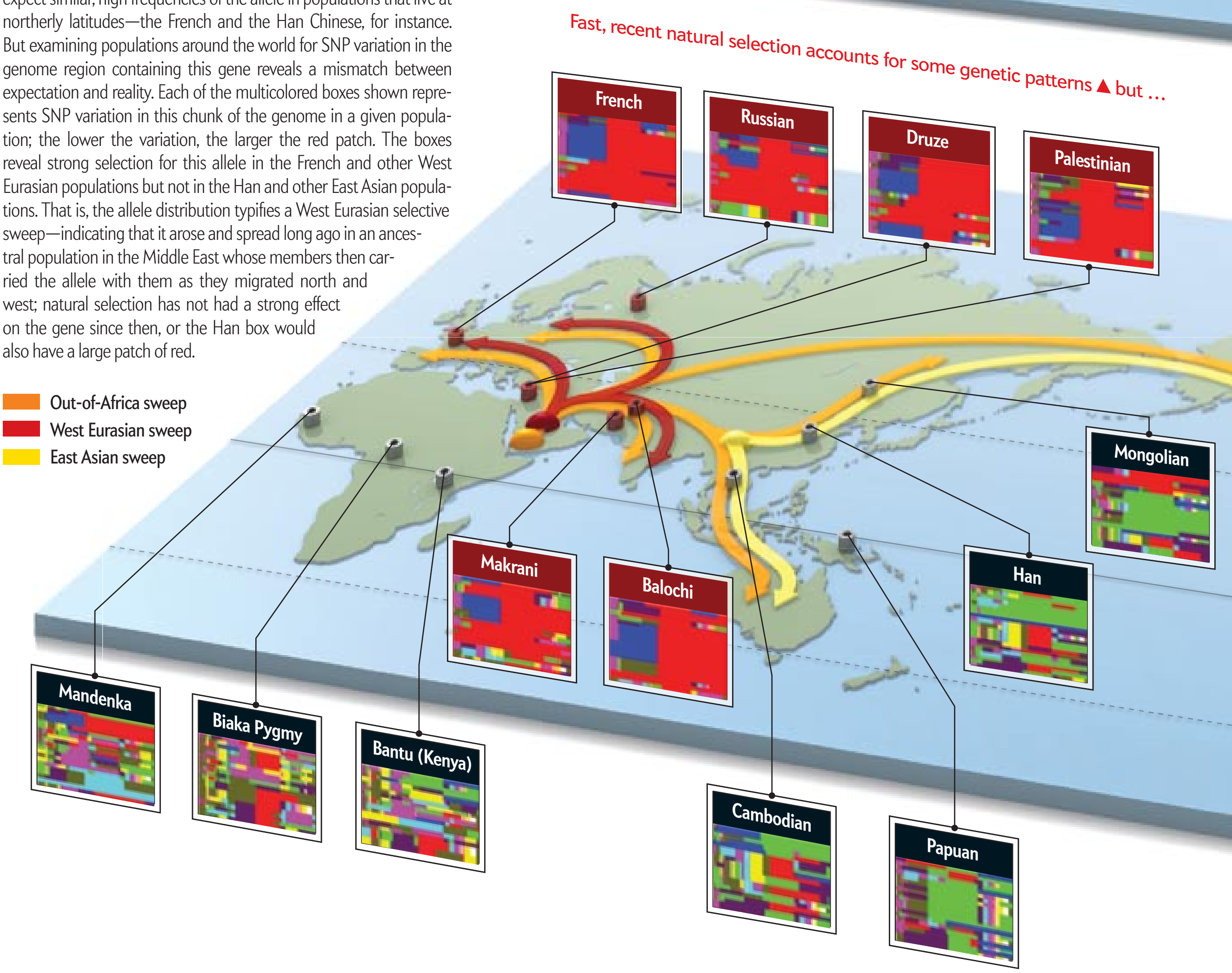
Researchers have identified a handful of favorable alleles that spread to high frequency as a result of strong natural selection acting quickly to adapt people to local environmental pressures (*right*). A new analysis of hundreds of other apparent signals of natural selection (such as sweeps) suggests, however, that most do not represent recent adaptations. Most of the selected alleles detected in this study exhibit one of just three geographical patterns (*bottom map*): either they occur at high frequency in all populations outside of Africa but not within Africa (*orange arrow*); or they are common throughout West Eurasia—an area composed of Europe and West and South Asia—but rare elsewhere (*red arrow*); or they dominate in North Asia, East Asia, Oceania and the Americas (*yellow arrow*) but occur only at low frequency in West Eurasia. These patterns suggests that ancient migrations have influenced where these alleles occur.

A gene known as *LARGE* that participates in the body's response to infection with the Lassa fever virus has undergone strong, recent natural selection in a population in Nigeria, where the pathogen is endemic.

The gene for the lactase enzyme that digests the sugar in milk has undergone rapid evolution among dairy-farming populations in Europe, the Middle East and East Africa over the past 5,000 to 10,000 years.



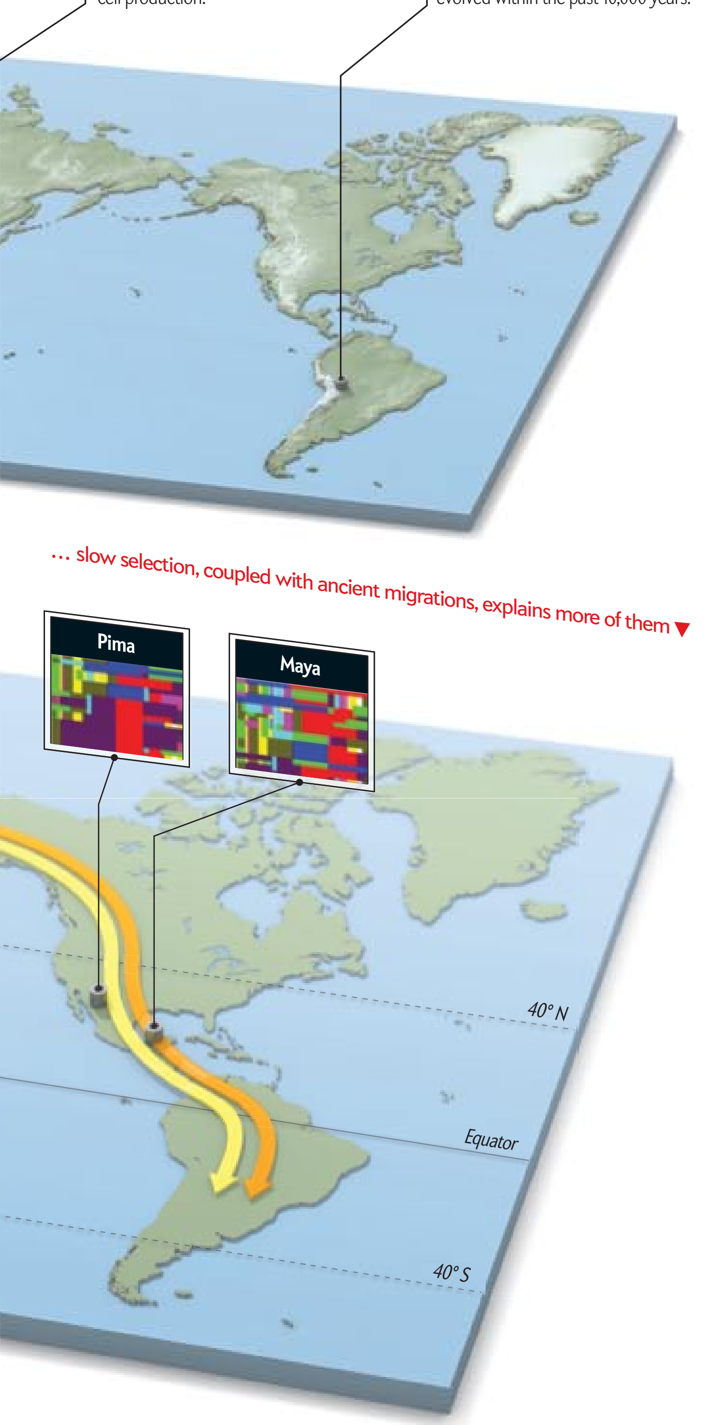
An example: a variant of the so-called *SLC24A5* gene that lightens skin color. It is an adaptation to reduced sunlight, so one would expect similar, high frequencies of the allele in populations that live at northerly latitudes—the French and the Han Chinese, for instance. But examining populations around the world for SNP variation in the genome region containing this gene reveals a mismatch between expectation and reality. Each of the multicolored boxes shown represents SNP variation in this chunk of the genome in a given population; the lower the variation, the larger the red patch. The boxes reveal strong selection for this allele in the French and other West Eurasian populations but not in the Han and other East Asian populations. That is, the allele distribution typifies a West Eurasian selective sweep—indicating that it arose and spread long ago in an ancestral population in the Middle East whose members then carried the allele with them as they migrated north and west; natural selection has not had a strong effect on the gene since then, or the Han box would also have a large patch of red.



Maps by Emily Cooper

A rare variant of a gene called hypoxia-inducible factor 2-alpha has spread to high frequency in Tibetans over the past few thousand years, helping to mitigate the ill effects of living at altitudes up to 14,000 feet above sea level by adjusting red blood cell production.

Among women who inhabit the Bolivian Altiplano, which rises some 12,000 feet above sea level, the uterine artery undergoes accelerated growth during pregnancy compared with the growth seen in women from low-lying regions—an adaptation that has evolved within the past 10,000 years.



SOURCE: "THE ROLE OF GEOGRAPHY IN HUMAN ADAPTATION," BY GRAHAM COOP ET AL., IN *PLOS GENETICS*, VOL. 5, NO. 6; JUNE 2009 (*haplotype patterns*)

through a group because of natural selection, it takes a surrounding chunk of the chromosome with it in a process called genetic hitchhiking. As the frequency of the beneficial allele increases in the group over time, so, too, do the frequencies of nearby "neutral" and nearly neutral alleles that do not affect protein structure or amount appreciably but ride along with the selected allele. The resulting reduction or elimination of SNP variation in the region of the genome containing a beneficial allele is termed a selective sweep. The spread of selected alleles by natural selection can also leave other distinctive patterns in the SNP data: if an existing allele suddenly proves particularly helpful when a population finds itself in new circumstances, that allele can reach high frequency (while remaining rare in other populations) without necessarily generating a hitchhiking signal.

Over the past few years multiple studies, including one my colleagues and I published in 2006, have identified several hundred genome signals of apparent natural selection that occurred within the past 60,000 years or so—that is, since *H. sapiens* left Africa. In a few of these cases, scientists have a pretty good grasp on the selective pressures and the adaptive benefit of the favored allele. For example, among dairy-farming populations in Europe, the Middle East and East Africa, the region of the genome that houses the gene for the lactase enzyme that digests lactose (the sugar in milk) shows clear signs of having been the target of strong selection. In most populations, babies are born with the ability to digest lactose, but the lactase gene turns off after weaning, leaving people unable to digest lactose as adults. Writing in the *American Journal of Human Genetics* in 2004, a team at the Massachusetts Institute of Technology estimated that variants of the lactase gene that remain active into adulthood achieved high frequency in European dairy-farming groups in just 5,000 to 10,000 years. In 2006 a group led by Sarah Tishkoff, who is now at the University of Pennsylvania, reported in *Nature Genetics* that they had found rapid evolution of the lactase gene in East African dairy-farming populations. These changes were surely an adaptive response to a new subsistence practice.

Researchers have also found pronounced signals of selection in at least half a dozen genes involved in determining skin, hair and eye color in non-Africans. Here, too, the selective pressure and adaptive benefit are clear. As humans moved out of their tropical homeland, they received reduced ultraviolet radiation from the sun. The body requires UV radiation to synthesize vitamin D, an essential nutrient. In the tropics, UV radiation is strong enough to penetrate dark skin in amounts needed for vitamin D synthesis. Not so in the higher latitudes. The need to absorb adequate amounts of vitamin D almost certainly drove the evolution of lighter skin color in these locales, and changes in these genes that bear signals of strong selection enabled that adaptive shift.

Selection signals also show up in a variety of genes that confer resistance to infectious diseases. For instance, Pardis Sabeti of Harvard University and her colleagues have found a mutation in the so-called *LARGE* gene that has recently spread to high frequency in the Yoruba of Nigeria and is probably a response to the relatively recent emergence of Lassa fever in this region.

MIXED SIGNALS

THOSE EXAMPLES and a small number of other cases provide strong evidence of natural selection acting quickly to promote helpful alleles. For most of the rest of the hundreds of candidate signals, however, we do not yet know which circumstances

favored the spread of the selected allele, nor do we know what effect the allele exerts on the people who harbor it. Until recently we and others interpreted these candidate signals to mean that there have been at least a few hundred very rapid selective sweeps within the past 15,000 years in several human populations that have been studied. But in newer work my colleagues and I have found evidence suggesting that instead most of these signals are not actually the result of very recent, rapid adaptation to local conditions at all.

Working with collaborators at Stanford University, we studied a massive SNP data set generated from DNA samples obtained from about 1,000 individuals from around the world. When we looked at the geographical distributions of selected alleles, we found that the most pronounced signals tend to fall into one of just three geographical patterns. First there are the so-called out-of-Africa sweeps, in which the favored allele and its hitchhikers exist at high frequency in all non-African populations [*see box on preceding two pages*]. This pattern suggests that the adaptive allele appeared and began to spread very shortly after humans left Africa but while they were still restricted to the Middle East—thus perhaps around 60,000 years ago—and was subsequently carried around the globe as humans migrated north and east. Then there are two other, more restricted, geographical patterns: the West Eurasian sweeps, in which a favored allele occurs at high frequency in all of the populations of Europe, the Middle East, and Central and South Asia, but not elsewhere; and the East Asian sweeps, in which the favored allele is most common in East Asians, as well as usually Native Americans, Melanesians and Papuans. These two patterns probably represent sweeps that got under way shortly after the West Eurasians and East Asians split off and went their separate ways. (It's not known precisely when this occurred, but probably around 20,000 to 30,000 years ago.)

These sweep patterns reveal something very interesting: ancient population movements have heavily influenced the distributions of favored alleles across the globe, and natural selection has done little to fine-tune those distributions to match modern environmental pressures. For example, one of the most important players in the adaptation to lighter skin color is a variant of the so-called *SLC24A5* gene. Because it is an adaptation to reduced sunlight, one might expect its frequency in the population to increase with latitude and its distribution to be similar in people from North Asia and Northern Europe. Instead we see a West Eurasian sweep: the gene variant and the hitchhiking DNA that travels with it are common from Pakistan to France but essentially absent in East Asia—even in the northern latitudes. This distribution indicates that the beneficial variant arose in the ancestral population of the West Eurasians—after they diverged from the ancestors of the East Asians—who carried it throughout that region. Thus, natural selection drove the beneficial *SLC24A5* allele to high frequency early on, but ancient population history helped to determine which populations today have it and which do not. (Other genes account for light skin in East Asians.)

A closer look at the selection signals in these and other data reveals another curious pattern. Most of the alleles with the most extreme frequency differences between populations—those that occur in nearly all Asians but no Africans, for example—do not exhibit the strong hitchhiking signals one would expect to see if natural selection swiftly drove these new alleles to high frequency. Instead these alleles seem to have propagated gradually during the roughly 60,000 years since our species set out from Africa.

In light of these observations, my collaborators and I now believe that textbook selective sweeps—in which natural selection drives an advantageous new mutation rapidly to fixation—have actually occurred fairly rarely in the time since the *H. sapiens* diaspora began. We suspect that natural selection usually acts relatively weakly on individual alleles, thus promoting them very slowly. As a result, most alleles experiencing selection pressure may attain high frequency only when the pressure persists for tens of thousands of years.

ONE TRAIT, MANY GENES

OUR CONCLUSIONS MAY SEEM PARADOXICAL: if it usually has taken 50,000, not 5,000, years for a helpful allele to spread through a population, how would humans ever manage to adapt quickly to new conditions? Although the best understood adaptations arise from changes in a single gene, it may be that most adaptations do not arise that way but rather stem from genetic variants having mild effects on hundreds or thousands of relevant genes from across the genome—which is to say they are polygenic. A series of papers published in 2008, for example, identified more than 50 different genes that influence human height, and certainly many more remain to be found. For each of these, one allele increases average height by just three to five millimeters compared with the other allele.

It is possible that human genomes have undergone more adaptive change recently than scientists can yet identify by examining the genome in the usual way.

When natural selection targets human height—as has occurred in the pygmy populations that live in rain forest habitats in Africa, Southeast Asia and South America, where small body size may be an adaptation to the limited nutrition available in these environments—it may operate in large part by tweaking the allele frequencies of hundreds of different genes. If the "short" version of every height gene became just 10 percent more common, then most people in the population would quickly come to have more "short" alleles, and the population would be shorter overall. Even if the overall trait were under strong selection, the strength of selection on each individual height gene would still be weak. Because the selection acting on any one gene is weak, polygenic adaptations would not show up in genome studies as a classic signal of selection. Thus, it is possible that human genomes have undergone more adaptive change recently than scientists can yet identify by examining the genome in the usual way.

STILL EVOLVING?

AS TO WHETHER HUMANS ARE STILL EVOLVING, it is difficult to catch natural selection in the act of shaping present-day populations. It is, however, easy to imagine traits that might be affected. Infectious diseases such as malaria and HIV continue to exert potent selection forces in the developing world. The handful of

known gene variants that provide some measure of protection against these scourges are probably under strong selective pressure, because people who carry them are more likely to survive and live to have many more children than those who do not. A variant that shields carriers from the vivax form of malaria has become ubiquitous in many populations in sub-Saharan Africa. The variants that protect against HIV, meanwhile, could spread throughout sub-Saharan Africa in hundreds of years if the virus were to persist and continue to be thwarted by that resistance gene. But given that HIV is evolving faster than humans are, we are more likely to overcome that problem with technology (in the form of a vaccine) than with natural selection.

In the developed world relatively few people die between birth and adulthood, so some of the strongest selection forces are probably those acting on genes that affect the number of children each person produces. In principle, any aspect of fertility or reproductive behavior that genetic variation affects could be the target of natural selection. Writing in the *Proceedings of the National Academy of Sciences USA* in 2009, Stephen C. Stearns of Yale University and his colleagues reported on the results of a study that identified six different traits in women that are associated with higher lifetime numbers of children and that all show intermediate to high heritability. Women with larger numbers of children, the team found, tend to be slightly shorter and stouter than average and to have later age at menopause. Hence, if the environment stays constant, these traits will presumably become more common over time because of natural selection: the authors estimate that the average age at menopause will increase by about one year over the next 10 generations, or 200 years. (More speculatively, it is plausible that genetic variation influencing sexual behavior—or use of contraceptives—would be subject to strong selection, although just how strongly genes affect complex behaviors such as these remains unclear.)

Still, the rate of change of most traits is glacially slow compared with the rate at which we change our culture and technology and, of course, our global environment. And major adaptive shifts require stable conditions across millennia. Thus, 5,000 years from now the human milieu will no doubt be very different. But in the absence of large-scale genomic engineering, people themselves will probably be largely the same. SA

MORE TO EXPLORE

Positive Natural Selection in the Human Lineage. P. C. Sabeti et al. in *Science*, Vol. 312, pages 1614–1620; June 16, 2006.

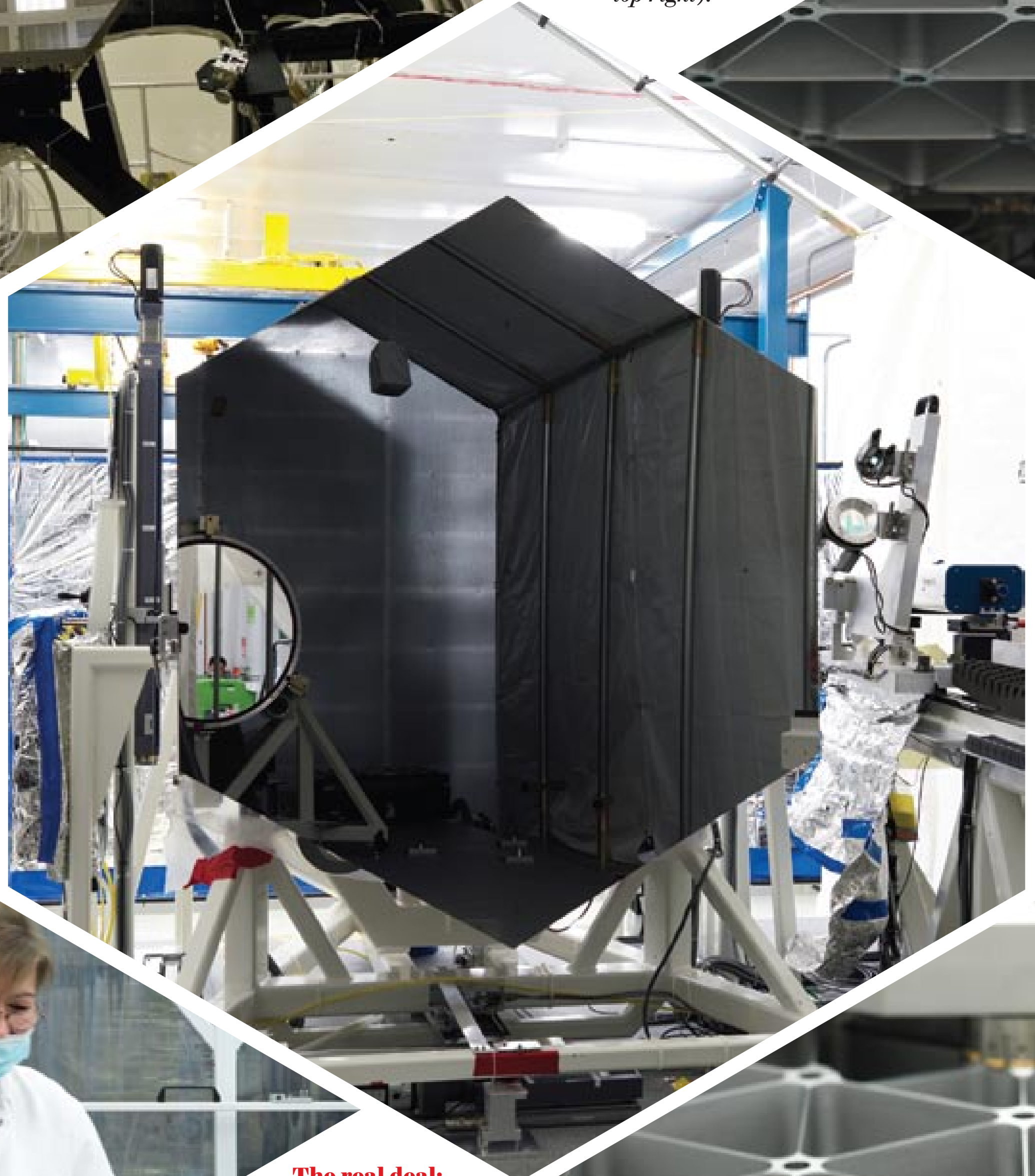
The Role of Geography in Human Adaptation. Graham Coop et al. in *PLoS Genetics*, Vol. 5, No. 6, e1000500; June 5, 2009.

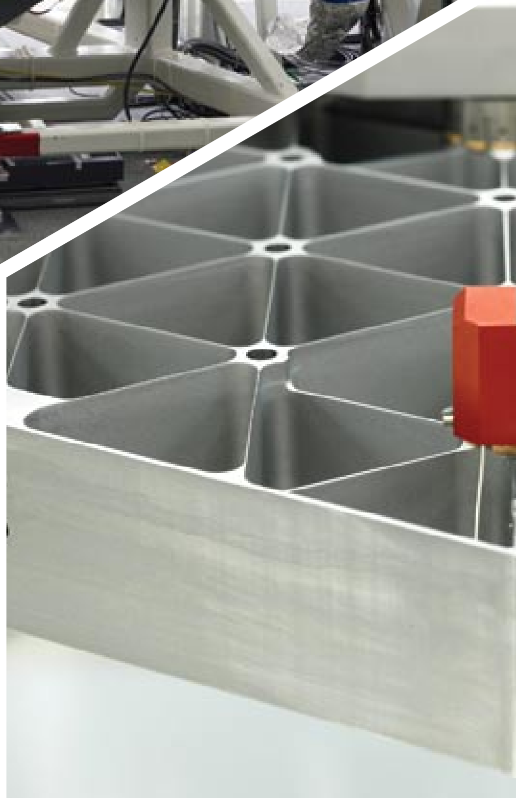
Sequencing of 50 Human Exomes Reveals Adaptation to High Altitude. Xin Yi et al. in *Science*, Vol. 329, pages 75–78; July 2, 2010.

Measuring Selection in Contemporary Human Populations. Stephen C. Stearns et al. in *Nature Reviews Genetics*, Vol. 11, pages 611–622; August 10, 2010.

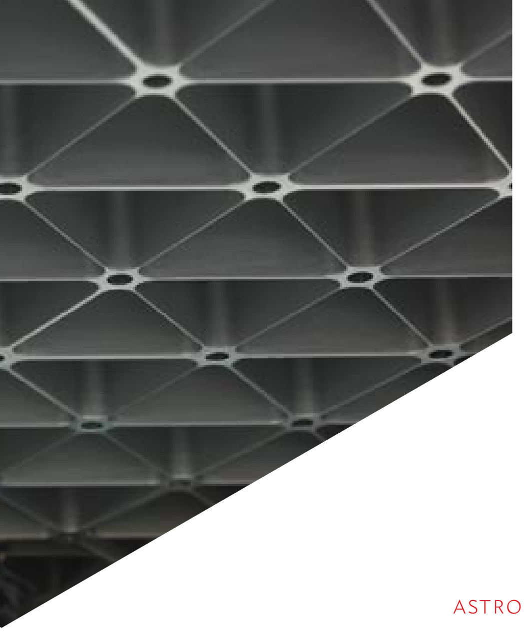
COMMENT ON THIS ARTICLE www.ScientificAmerican.com/oct2010


Ready to test: Segments of the James Webb Space Telescope's mirror are mounted for testing in an ultracold chamber (*top left and top right*).



The real deal: Each four-foot-wide segment of the Webb's mirror is made of beryllium, a difficult material to polish and test (*middle and bottom rows*).

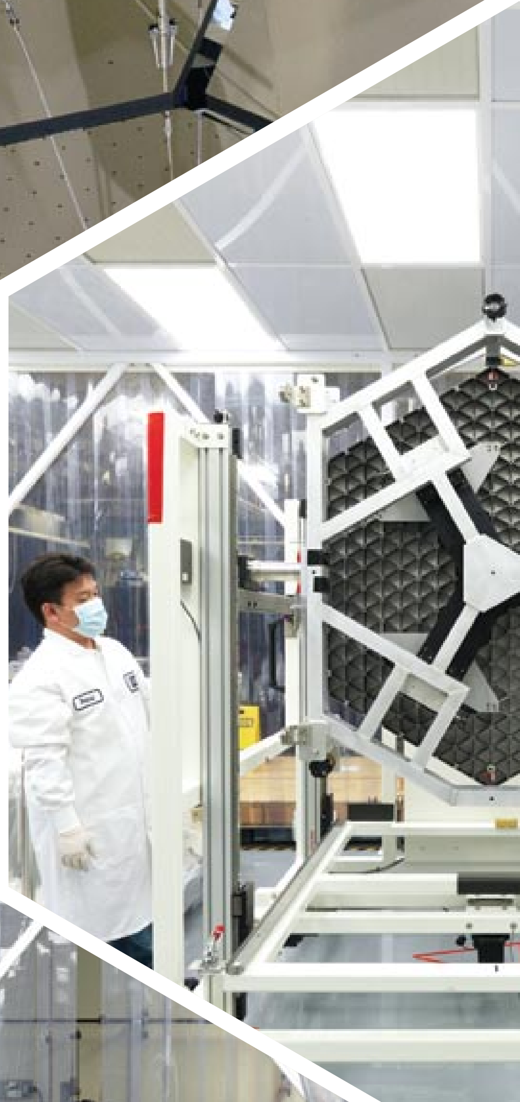


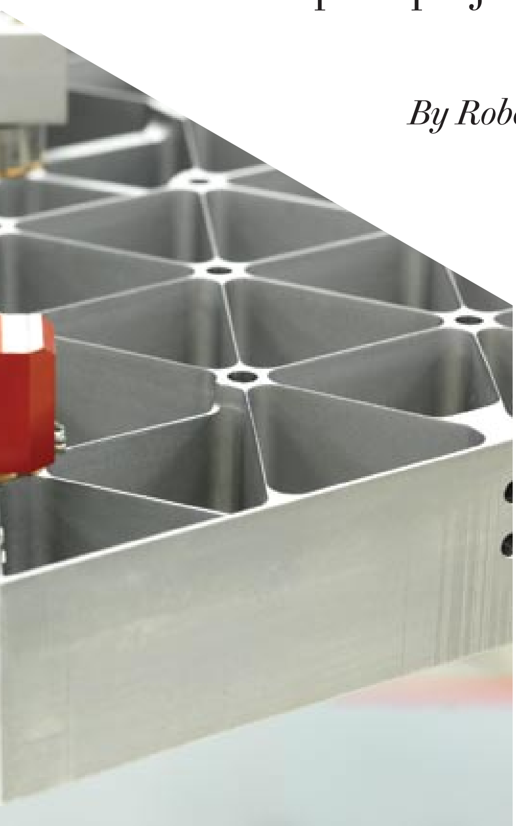
ASTRONOMY

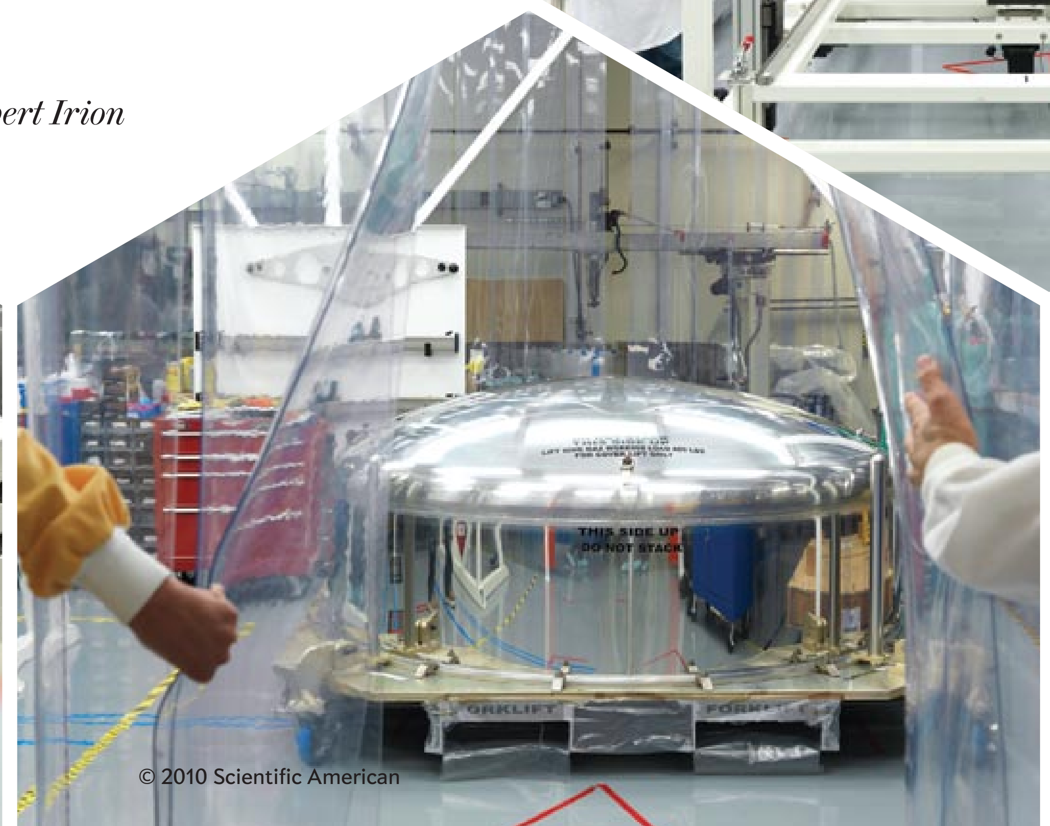
Origami Observatory

NASA is building an innovative and risky space telescope that promises to surpass the hugely successful Hubble. Here's an exclusive, behind-the-scenes look at the most audacious space project in decades

By Robert Irion







Robert Irion, a former correspondent for *Science,* directs the Science Communication Program at the University of California, Santa Cruz. He writes about astronomy for *Smithsonian* and other national magazines.

THE MIRROR, A PERFECT HEXAGON OF gunmetal gray, stands vertically on a low platform. It is about two inches thick and more than four feet wide, a precisely carved slab of beryllium that gleams in the low light of this optics laboratory near San Francisco Bay. My guide, chief engineer Jay Daniel, watches my footing as I step gingerly in front of the mirror to see my reflection. "It's like your bathroom mirror," Daniel says, chuckling.

The other side of this looking glass, though, is nothing like a household vanity. The slab of metal is mostly hollow, drilled out by machinists to leave an intricate triangular scaffold of narrow ribs. It is beautiful in its geometric precision, and I resist the urge to touch one of the knifelike edges. The polished front layer that remains, Daniel says, is a mere 2.5 millimeters thick. From its starting weight of 250 kilograms, the entire mirror now weighs just 21 kilos. That is light enough for a rocket to hoist 18 of them deep into space, where the curved mirrors will join as one to form the heart of the most audacious space observatory ever launched.

That observatory, a $5-billion NASA mission (in partnership with the European and Canadian space agencies) called the James Webb Space Telescope, or JWST, is scheduled to carry on in 2014 as a successor to the iconic Hubble Space Telescope. The Hubble has circled 570 kilometers above Earth since 1990, giving astronomers their sharpest views of galaxies in the distant universe and of the births and deaths of stars closer to home. Like the Hubble, the Webb promises stunning images of the cosmos, but with far more penetrating vision. Astronomers have designed it to stare back toward the beginning of the universe. It may spot the explosions of the first stars that arose after the big bang and reveal the origins of galaxies similar to our Milky Way. It also will look deeply into clouds of gas and dust, the wombs of gestating stars and their families of planets.

To meet these goals, the Webb will be radically different from its predecessor. Its lightweight mirror will span more than 6.5 meters, giving it six times the light-collecting power of the Hubble's 2.4-meter-wide mirror. Coated with gold, the telescope's 18 hexagonal panels will act as a uniform surface—a feat requiring them to align within one ten-thousandth the width of a human hair. NASA will hurl this honeycombed eye into a looping orbit far beyond the moon. Along the way, it will unfurl a giant sunshield, casting a frigid shadow in which the mercury will fall below 55 kelvins so the telescope can sense traces of light and warmth that have straggled across the universe for more than 13 billion years.

All this involves unprecedented technical risks. Because of the telescope's remote perch, no astronaut will be able to fix it if something goes wrong. Unlike with the Hubble, which has had several repairs and upgrades throughout the two decades it has been in operation, there will be no do-overs, no shuttle flight to correct an embarrassing optical flaw, no widget to get that pesky shield unstuck. What's more, to get to its lonely orbit, the probe must first fold up to fit in the cramped cargo bay of an Ariane 5 rocket. Hitching that ride puts strict limits on the telescope's weight and dimensions. The observatory must then deploy itself with balletic precision, a tortuous sequence that ends with two folded panels of mirror segments rising into place like the sides of a drop-leaf dining table.

"I think of it as the origami telescope," says Mark Clampin, the observatory project scientist at the NASA Goddard Space Flight Center in Greenbelt, Md. "We have to unpack it, align it and have it work at the right temperature. It's not designed to be serviced, so everything has to work on the day."

The combination of mass, size and temperature constraints—and the mechanical derring-do required to pull it off—has forced NASA to spend far more money on the Webb than astronomers had hoped. A national panel in 2001 ranked the space observatory as astronomy's top priority and called for a $1-billion budget, but that figure was naive. It did not include costs to launch and operate the telescope, and it grossly missed the mark on how complex and time-consuming the design would become. "The [engineering] challenges are much greater than initially anticipated," says Webb program scientist Eric P. Smith of NASA headquarters in Washington, D.C.

The project's costs are not far out of line with those of other pioneering satellites, Smith notes. For instance, the Chandra X-ray Observatory (now orbiting Earth) and the Cassini spacecraft (now touring Saturn and its exotic rings and moons) each cost roughly $4 billion for their complete life cycles, in 2007 dollars. "This is what it costs to build a big flagship mission," says Alan Dressler of the Carnegie Observatories in Pasadena, Calif., who chaired the first report on the Hubble's successor in 1995. The Webb is "being built quite effectively, and money is not being wasted," he says.

Some dismayed researchers think the observatory saps a dis-

IN BRIEF

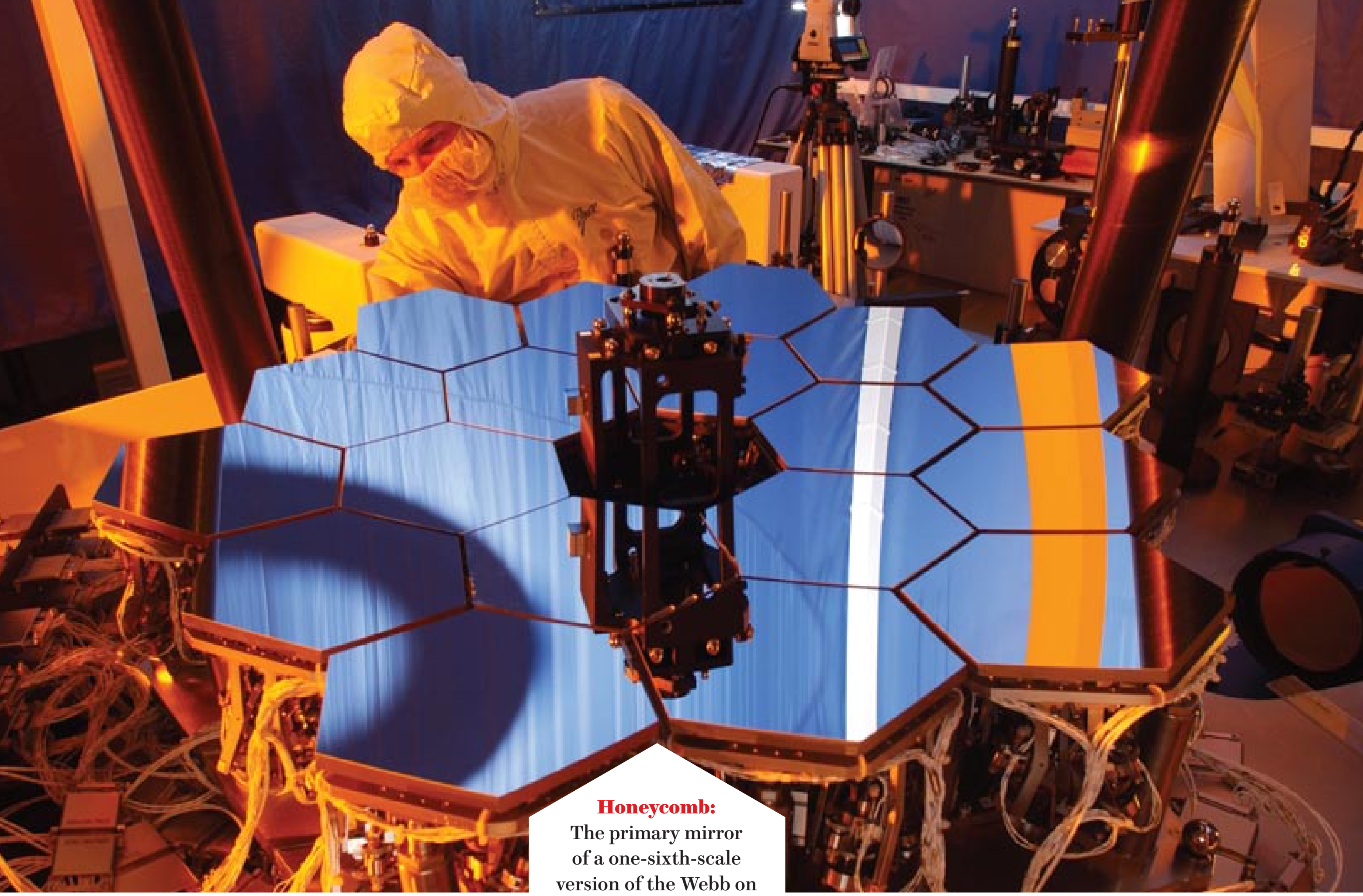
When the Hubble Space Telescope retires in a few years, a NASA-led collaboration plans to replace it with a telescope of an entirely new generation.

The James Webb Space Telescope's ultralight, shape-adjusting mirrors will have six times the light-collecting power of those of the Hubble, and its instruments will be sensitive in parts of the spectrum where most telescopes have been lacking.

Infrared radiation will open new vistas on the earliest ages of the universe, when the first stars and galaxies formed, and also on planets orbiting other stars in our galaxy.

The most delicate part of the mission will be when the telescope and its giant heat shields unfurl out of the rocket that will carry them into orbit. Even a small technical glitch could render the $5-billion observatory inoperable.

PRECEDING PAGES: JUSTIN FANTL; COURTESY OF NASA/MSFC/EMMETT GIVENS (*top right and top left*)



Honeycomb: The primary mirror of a one-sixth-scale version of the Webb on a test bed. It has 18 beryllium segments, with the instruments in the middle.

proportionate share of NASA's astronomy budget, shutting out other missions. "The opportunity cost of JWST is very high, and it will be felt throughout the decade," says astrophysicist Shrinivas Kulkarni of the California Institute of Technology. In particular, he says, advanced probes to explore gravitational waves, the high-energy universe, and the details of possible planets like Earth around other stars must now wait until the 2020s and beyond.

Even the Webb's supporters are on edge about whether this huge investment will pay off in a mission that works as advertised. "This is a really challenging project," says Garth Illingworth of the University of California, Santa Cruz, a longtime Hubble user. "Even by the standards of most NASA projects, this is a tough one. For most of the things on JWST, if it doesn't deploy, it's dead."

THE UNDISCOVERED COUNTRY

MOST OF THE TELESCOPE'S SHAPE-CHANGING will occur before it reaches its home in the solar system: a gravitational balancing point called L2, more than one million kilometers in deep space. There the spacecraft will use tiny shots of fuel to follow Earth's pace in a gentle, undisturbed orbit around the sun. Engineers think it will have enough fuel to last a decade or so until they can no longer steer it. (NASA's budget covers five years of operations; extending it five more years would add $500 million.)

Astronomers knew they would have to propel the satellite far away when they began planning it 15 years ago. The Hubble basks in the unwelcome glow of Earth, which means it has to operate at close to room temperature. It is therefore blind to faint infrared light from the distant objects astronomers would dearly like to see: the earliest ancestors of today's galaxies, scattered at the margins of the visible universe. Their light would have been visible to our eyes—and to the Hubble's cameras—back then. But as the cosmos expanded in the intervening billions of years, the light's waves have stretched out of the visible spectrum and into the infrared.

"This is where the new opportunity exists," says chief project scientist John C. Mather, a Nobel laureate at NASA Goddard. "This is the rock we've never turned over, the place we've never looked. We don't know what the first objects were that lit up after the big bang, and we ought to go find out."

Named for NASA's administrator during the Apollo era, the James Webb Space Telescope will use infrared cameras and other detectors to sense the first shards of galaxies as they assembled into the kind of majestic bodies we see today. Those embryonic objects probably existed 400 million years or so after the big bang—just 3 percent of the universe's current age. Its cameras may detect the sparks of even earlier stars, behemoths with hundreds of times the mass of our sun. Such stars would have detonated after short, brilliant lives, casting flares of light that still travel across the cosmos.

"We are going to extraordinary lengths to build a far more challenging telescope than the Hubble, to be able to see back as far as we will ever see," says Carnegie's Dressler. "NASA had a strong desire to build the first of the new telescopes, rather than the last of the old."

Infrared light also opens a portal toward objects closer to us, enabling us to see through the shrouds of dust that hide the nurseries of stars and planets in our galaxy. Right now astronomers

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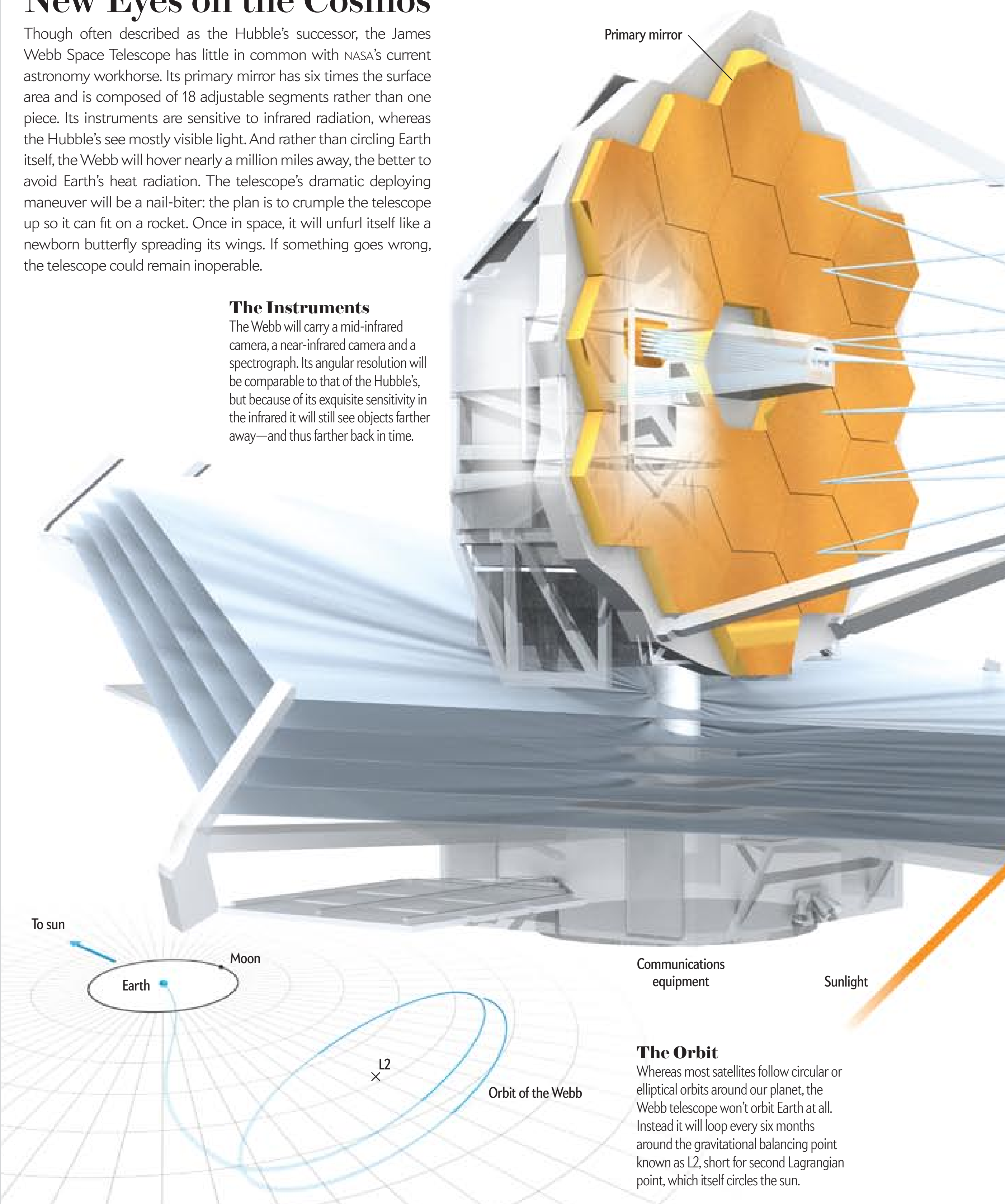
New Eyes on the Cosmos

Though often described as the Hubble's successor, the James Webb Space Telescope has little in common with NASA's current astronomy workhorse. Its primary mirror has six times the surface area and is composed of 18 adjustable segments rather than one piece. Its instruments are sensitive to infrared radiation, whereas the Hubble's see mostly visible light. And rather than circling Earth itself, the Webb will hover nearly a million miles away, the better to avoid Earth's heat radiation. The telescope's dramatic deploying maneuver will be a nail-biter: the plan is to crumple the telescope up so it can fit on a rocket. Once in space, it will unfurl itself like a newborn butterfly spreading its wings. If something goes wrong, the telescope could remain inoperable.

The Instruments

The Webb will carry a mid-infrared camera, a near-infrared camera and a spectrograph. Its angular resolution will be comparable to that of the Hubble's, but because of its exquisite sensitivity in the infrared it will still see objects farther away—and thus farther back in time.



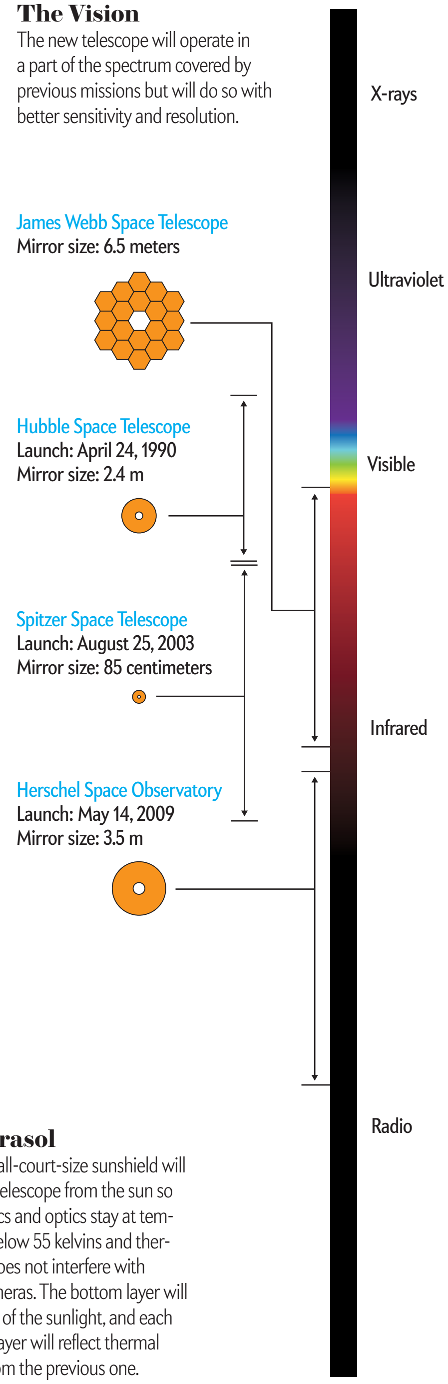
The Orbit

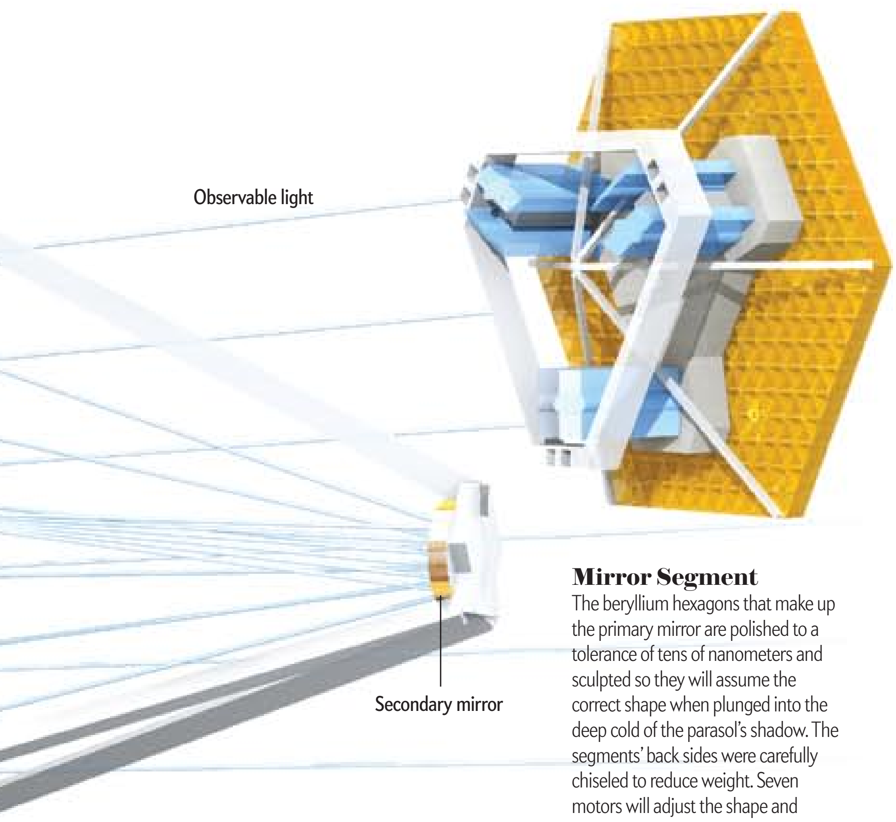
Whereas most satellites follow circular or elliptical orbits around our planet, the Webb telescope won't orbit Earth at all. Instead it will loop every six months around the gravitational balancing point known as L2, short for second Lagrangian point, which itself circles the sun.

Illustration by Bryan Christie

The Vision

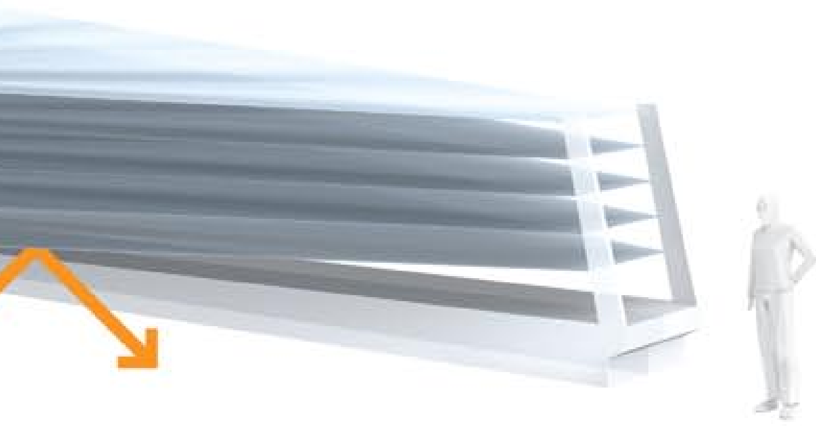
The new telescope will operate in a part of the spectrum covered by previous missions but will do so with better sensitivity and resolution.





Mirror Segment

The beryllium hexagons that make up the primary mirror are polished to a tolerance of tens of nanometers and sculpted so they will assume the correct shape when plunged into the deep cold of the parasol's shadow. The segments' back sides were carefully chiseled to reduce weight. Seven motors will adjust the shape and orientation of each segment, with an accuracy of tens of nanometers, to respond to small thermal deformations that would reduce image quality.

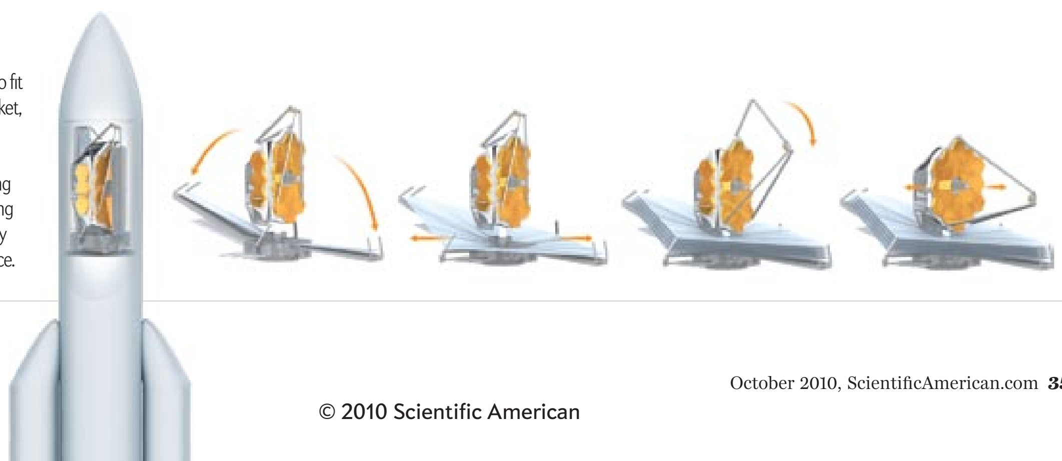


The Parasol

The volleyball-court-size sunshield will shelter the telescope from the sun so its electronics and optics stay at temperatures below 55 kelvins and thermal noise does not interfere with infrared cameras. The bottom layer will reflect most of the sunlight, and each successive layer will reflect thermal radiation from the previous one.

The Chrysalis

The six-tonne telescope is too large to fit inside an Ariane 5—or inside any rocket, for that matter. Instead it will launch with six of its mirror segments folded back like the sides of a drop-leaf dining table. The secondary mirror scaffolding and the sunshield will also unfold only after the telescope reaches deep space.



WHAT THE NEW OBSERVATORY WILL SEE

Going Deep with James Webb

The James Webb Space Telescope was designed to look farther into cosmic history than does NASA's flagship observatory, the Hubble Space Telescope. The Webb's infrared eyes will also peer more closely at the nurseries of newborn stars in our galaxy, as well as at faint objects in our solar system. The five-year mission will address four main questions:

- How did the cosmic dark ages end? The Webb should be sensitive enough to see the earliest shining objects that began to clear out the dark fog of the new universe about 180 million years after the big bang: the first generations of giant stars and their supernova explosions.
- How do galaxies such as the Milky Way form? Images from the Webb will trace how galaxies grew within the hidden cocoons of dark matter that—together with black holes in their cores—guided their formation.
- How are stars and planets made? Our sun was born in a cold knot of dust and gas. Earth and the other planets then coalesced within a disk that swirled around the new star. The telescope will unveil those processes in detail by staring deeply into dusty clouds where stars are just now beginning to shine.
- Could life exist elsewhere? Our planet, and our solar system, had the right conditions for life. The Webb will study these families of planets around nearby stars, as well as comets and primitive asteroids orbiting our sun, for clues about how life gained a toehold. *—R.I.*

detect alien planets mostly using the visible spectrum of light, so they are able to see only objects in systems that have "cleared out" of the disks of gas and rocky debris that created them. But because infrared light can penetrate through dust, the Webb will unveil many stages in those acts of creation, helping us determine whether our solar system is rare or common. Some of the planets will cross in front of their stars, giving the sharp-eyed Webb a chance to detect gases in their atmospheres. It is a long shot, but the telescope just might find a planet with an unstable mixture of gases, such as oxygen, carbon dioxide and methane—the first signs of life elsewhere.

BERYLLIUM DOES IT BETTER

OTHER SPACE TELESCOPES have used small mirrors made of beryllium, the second-lightest metal. And the Webb's 6.5-meter primary mirror is not huge, by astronomy standards: several telescopes on the ground now have mirrors ranging from eight to 10 meters across, with far bigger ones on the drawing board. But creating 18 beryllium segments to form a single, smooth surface in deep space has taxed optical technicians as never before.

It is a challenge embraced by the engineers at Tinsley, an optics company in Richmond, just north of Berkeley, Calif., owned by L-3 Communications. Before my visit—the first time Tinsley has allowed a journalist to see its work on the mirrors—Daniel asks me not to bring a camera and lets me know that some questions are off-limits. Making telescope mirrors is intensely competitive; Tinsley has spent years and millions of dollars perfecting NASA's prescription for the Webb and its metallic eyes.

When I arrive, I learn in a briefing that beryllium powder is toxic. I must sign a waiver that absolves Tinsley in case of pulmonary distress. Not to worry, Daniel assures me: the lab polishes its mirrors only with wet processes, so there is no dust floating around. My lungs can relax—although at times I wear a surgical mask to keep a sniffle from soiling the beryllium.

In the project's early days, astronomers assumed they would use ultralow-expansion glass, which holds its shape when temperatures change. But when opticians made test mirrors and plunged them to the kind of bitter cold the telescope will experience, the glass warped in a way that might have thrown the telescope out of whack. In contrast, beryllium is stiff and well behaved in such conditions.

That change, though, added a year to the mirror's production schedule, because beryllium takes longer to polish. "It's extremely hard to make a beryllium mirror without leaving stresses in it," says optical engineer Bob Brown of Ball Aerospace & Technologies in Boulder, Colo., which oversees Tinsley's work on the telescope. Carving the surface makes the remaining metal want to bend upward, Brown says. The team must remove that layer of stressed metal by gently etching the mirror with acid or grazing it with a sharp tool. It is a tedious, exacting process.

> "NASA had a strong desire to build the first of the new telescopes, rather than the last of the old." *—Alan Dressler*

To view the mirrors, I don booties and a smock to keep stray beryllium off my shoes and clothing. Daniel and Brown escort me onto Tinsley's factory floor, built expressly for the Webb. Eight polishing machines, each about two stories high, dominate the room. A mirror segment sits on one of the computer-controlled machines. A black bellows, shaped like an accordion, makes a groaning sound as it gently moves a robot back and forth over the mirror. Attached to the tip of the robot is a Frisbee-size polishing head. The computer dictates how long the spinning polisher works on each spot to remove an exact amount of beryllium.

A whitish liquid, looking like diluted milk, lubricates the rotating head and flows off the sides of the mirror in a constant stream. When I ask Daniel what it is, he smiles. "It's a polishing fluid," he says after a pause. "It's a home brew. It's very specifically stipulated, and it's proprietary." Brown points to the edges of the hexagon. Within five millimeters of the border, he says, the mirror is still smooth, a difficult polishing feat never before tried on surfaces this large. If the margin were twice as wide, the telescope would focus 1.5 percent less starlight into a sharp image—a big loss of data from the faintest objects.

Opticians measure the precision of the mirrors' surface in Tinsley's metrology lab, an enclosed space with strict controls on temperature and air currents. The technicians use holograms, infrared lasers and other tools to gauge the height of the mirror's

surface at hundreds of thousands of points. A segment goes back and forth between the polishing machines and the metrology lab a couple of dozen times to get the shape and smooth finish that NASA requires.

Next, each segment is flown to Ball Aerospace, where engineers attach it to its flight hardware—a graphite composite structure that latches onto the hexagon's rear grid work and holds it in place in the telescope. Next, it travels to the NASA Marshall Space Flight Center in Huntsville, Ala., for testing in a large vacuum chamber cooled by liquid helium to 25 kelvins. In those conditions, the metal warps in subtle ways, which opticians map in microscopic detail. The segment then returns to California, where Tinsley uses the opticians' maps to guide additional, subtle polishing that will cancel out whatever warping the beryllium undergoes once it is subjected to the cold of space.

This slow waltz has been going on since December 2009. As of August, one mirror segment was done, and about half a dozen others were in their final polishing stages. Tinsley plans to deliver all 18 segments (plus three spares) to NASA by mid-2011.

LEARNING FROM THE HUBBLE

AS TINSLEY'S ENGINEERS WORK, the dramatic flaw of the Hubble Space Telescope is very much on their minds. The Hubble's mirror was polished to the wrong shape, thanks to a measuring error that engineers overlooked. Shuttle astronauts installed corrective mirrors three years after launch and saved the mission. No such option exists here.

Heeding the Hubble's lessons, NASA recruited engineers who helped to fix the Hubble to work on the new mission. The same technique used to diagnose the shape of the Hubble's deformed mirror by studying its blurry images will keep the Webb in sharp focus. "As we move the telescope across the sky, certain thermal gradients set in and the telescope gently drifts out of shape," says Matt Mountain, director of the Space Telescope Science Institute in Baltimore, which will oversee its operations. But unlike any other space observatory, the Webb telescope will have an active, adjustable mirror to compensate for those changes.

First, small lenses in the telescope's instruments will create out-of-focus images like the ones that plagued the Hubble. After analyzing those pictures, mission control will send radio signals to activate seven tiny motors on the back of each mirror segment. Each motor, built at Ball Aerospace, can push or pull on the mirror in increments of fewer than 10 nanometers. That gives astronomers control over each segment's curvature and its position relative to the neighboring hexagons. Mission control will perform that procedure and recalibrate the mirror every two weeks or so.

Of course, the telescope needs to deploy itself properly in the first place. In particular, two folded "leaves," each bearing three of the mirror segments, must swing properly to form the entire surface. A single, 75-centimeter-wide secondary mirror also must latch into its perch, on a spidery tripod seven meters above the main mirror, to reflect light back through the center of the primary and to the instruments that record the data.

But the transformation that really makes observers gulp is the opening of the enormous sunshield, which is 11 meters wide and 19 meters long. If it does not work, the sun's heat will blind the instruments to most of their targets. In a video simulation, the shield spreads out like a stack of five candy wrappers, each with the surface area of a volleyball court. NASA's prime contractor, Northrop Grumman in Redondo Beach, Calif., has designed satellites with giant, unfurling antennae—as well as so-called black operations in space for the government, according to NASA officials. But the Webb will be the most mechanically complex civilian mission of this type yet attempted.

Backbone: The Webb is so stiff it will not bend more than 32 nanometers, thanks to its structure of graphite composites, titanium and a nickel-steel alloy.

COURTESY OF NASA

Adding to the stress is that no cold vacuum chamber is big enough to test the entire sunshield before launch. To keep costs from growing even higher, NASA adopted a riskier procedure that tests critical pieces of the observatory—but never the whole thing. "That's life in the fast lane," Mountain says. "We're going to have to take an extra leap of faith."

For now the mission's scientists are focused on building the telescope and its instruments. But they cannot help looking past the 2014 launch, too. "At one level, this is our generation's contribution to civilization," says NASA Goddard's Lee Feinberg, the Webb's optical telescope element manager. "It won't last forever, but it will be out there in space. Future generations probably will be able to find it with big telescopes." And perhaps one day the observatory's golden mirror—pocked by space dust and weathered by radiation—will be towed back to Earth as a monument to the time when we first grasped our cosmic past. SA

MORE TO EXPLORE

The First Stars in the Universe. Richard B. Larson and Volker Bromm in *Scientific American*, Vol. 285, No. 6, pages 52–59; December 2001.

Origin of the Universe. Michael S. Turner in *Scientific American*, Vol. 301, No. 3, pages 22–29; September 2009.

Planets We Could Call Home. Dimitar D. Sasselov and Diana Valencia in *Scientific American*, Vol. 303, No. 2, pages 24–31; August 2010.

ANIMATIONS AT **www.jwst.nasa.gov/videos_deploy.html**

EXCLUSIVE POLL

In Science We Trust

Our Web survey of readers suggests that the scientifically literate public still trusts its experts—with some important caveats

SCIENTISTS HAVE HAD A ROUGH YEAR. THE LEAKED "CLIMATEGATE" e-mails painted researchers as censorious. The mild H1N1 flu outbreak led to charges that health officials exaggerated the danger to help Big Pharma sell more drugs. And Harvard University investigators found shocking holes in a star professor's data. As policy decisions on climate, energy, health and technology loom large, it's important to ask: How badly have recent events shaken people's faith in science? Does the public still trust scientists?

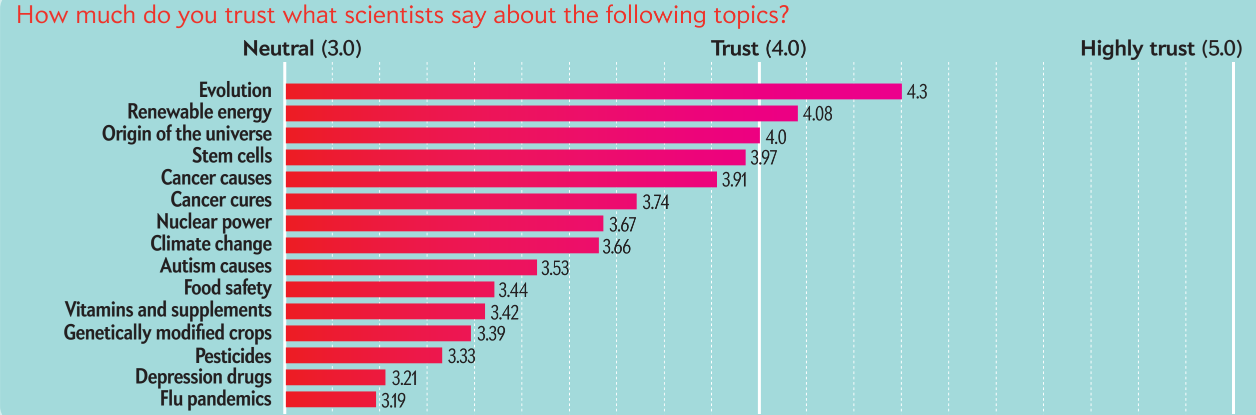
To find out, *Scientific American* partnered with our sister publication, *Nature*, the international journal of science, to poll readers online. More than 21,000 people responded via the Web sites of *Nature* and of *Scientific American* and its international editions. As expected, it was a supportive and science-literate crowd—19 percent identified themselves as Ph.Ds. But attitudes differed widely depending on particular issues—climate, evolution, technology—and on whether respondents live in the U.S., Europe or Asia.

How Much Do People Trust What Scientists Say?

We asked respondents to rank how much they trusted various groups of people on a scale of 1 (strongly distrust) to 5 (strongly trust). Scientists came out on top by a healthy margin. When we asked how much people trust what scientists say on a topic-by-topic basis, only three topics (including, surprisingly, evolution) garnered a stronger vote of confidence than scientists did as a whole.

Whom do you typically trust to provide accurate information about important issues in society?

How much do you trust what scientists say about the following topics?



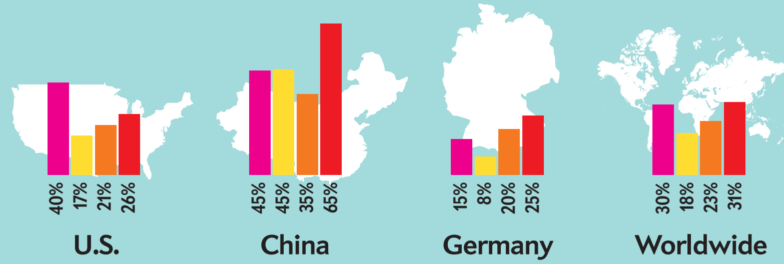
Graphic by Arno Ghelfi

When Science Meets Politics: A Tale of Three Nations

Should scientists get involved in politics? Readers differ widely depending on where they are from. Germany, whose top politician has a doctorate in quantum chemistry, seems to approve of scientists playing a big role in politics. Not so in China. Even though most leaders are engineers, Chinese respondents were much less keen than their German or U.S. counterparts to see scientists in political life.

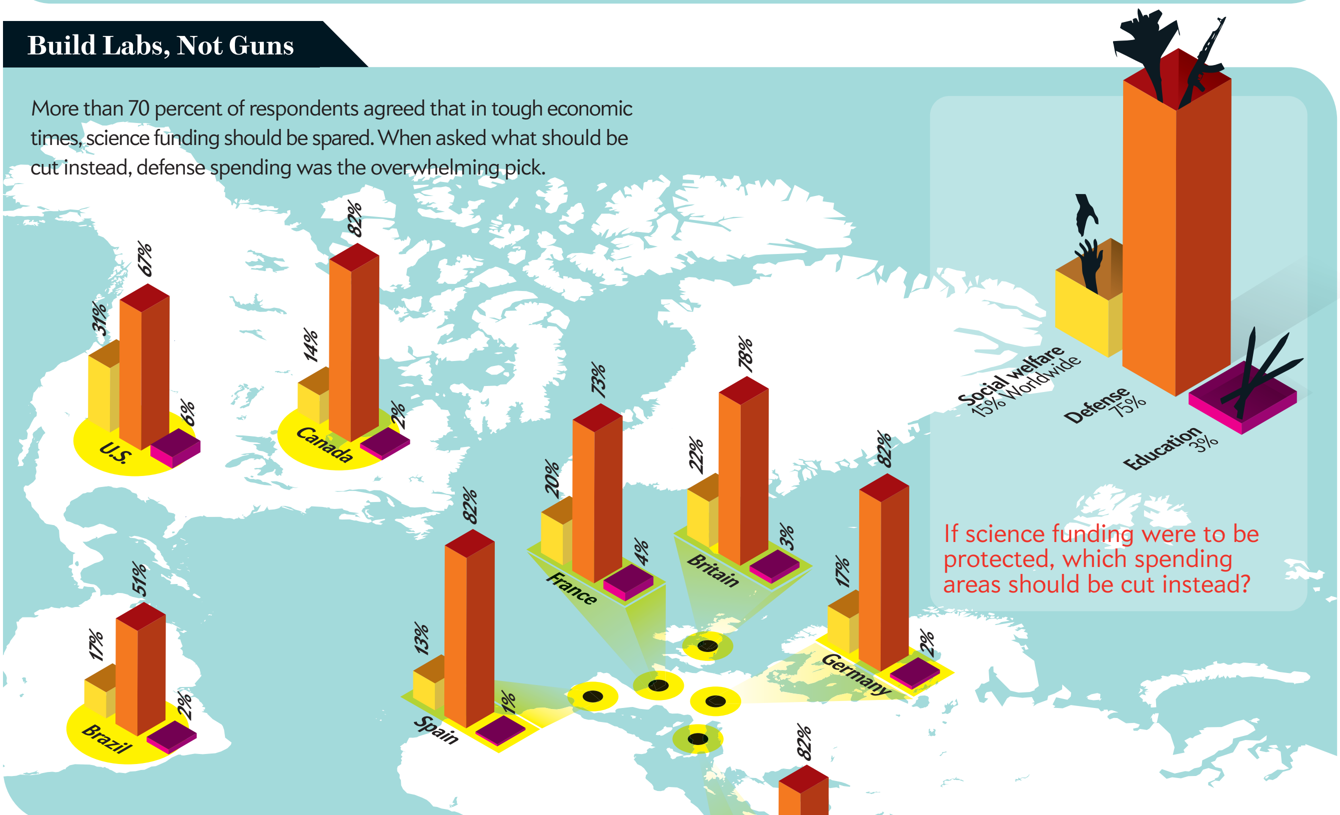
Respondents who agreed with the following statements

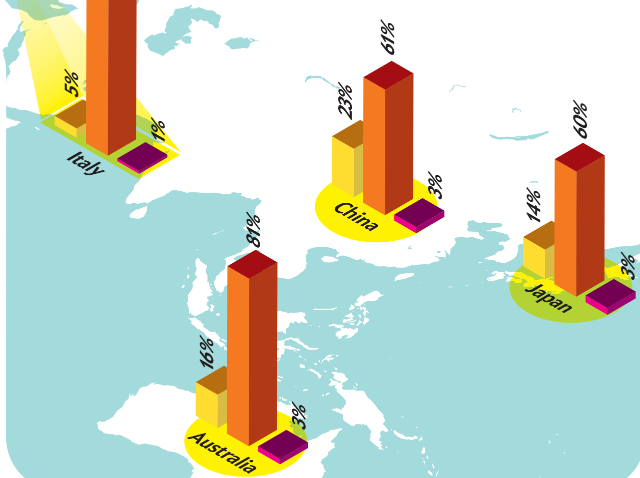
- Scientists should speak out about what the science says but avoid advocacy
- Scientists should stay out of politics
- Scientists know best what is good for the public
- Scientists should pay attention to the wishes of the public, even if they think citizens are mistaken or do not understand their work



Build Labs, Not Guns

More than 70 percent of respondents agreed that in tough economic times, science funding should be spared. When asked what should be cut instead, defense spending was the overwhelming pick.

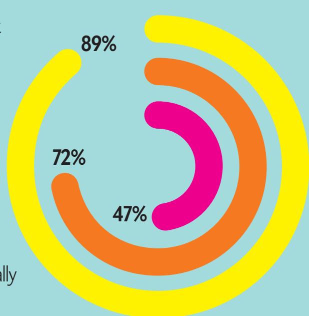




Is Science Worth Investing In?

Respondents who agreed with the following statements

- Investment in basic science may not have immediate payoffs for the economy, but it lays the foundation for future growth
- Investment in basic science is one of the best ways to stimulate the economy and create jobs
- Science doesn't necessarily lead to economic growth and should generally be supported for other reasons



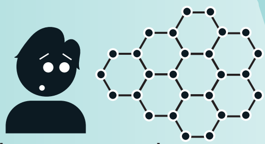
Techno Fears

Technology can lead to unintended consequences. We asked readers what technological efforts need to be reined in—or at least closely monitored. Surprisingly, more respondents were concerned about nuclear power than artificial life, stem cells or genetically modified crops.

47%

Nuclear power should be phased out and replaced with other sources of clean energy

26%



The government should act now to protect the public from the unknown risks of nanotechnology

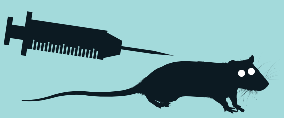
23%

I do not approve of research on chimps under any circumstances

22%

GM crops pose unacceptable environmental and health risks and should not be planted

12%

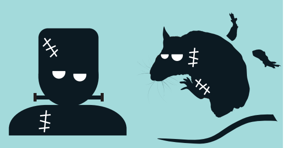


I do not approve of research on nonprimate mammals under any circumstances

8%

I do not approve of embryo research under any circumstances

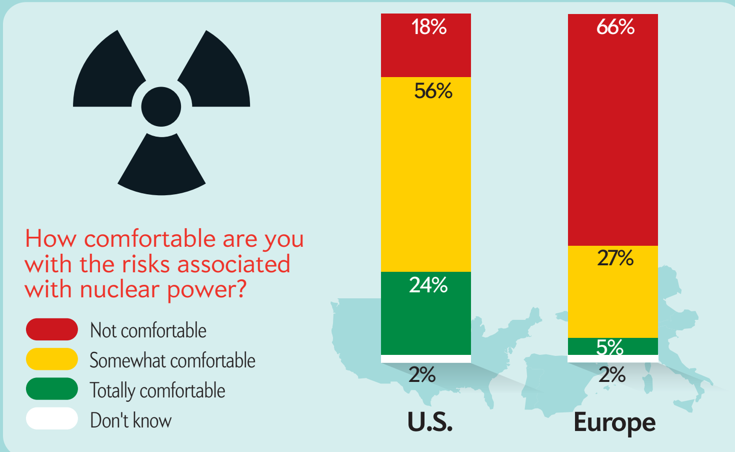
7%

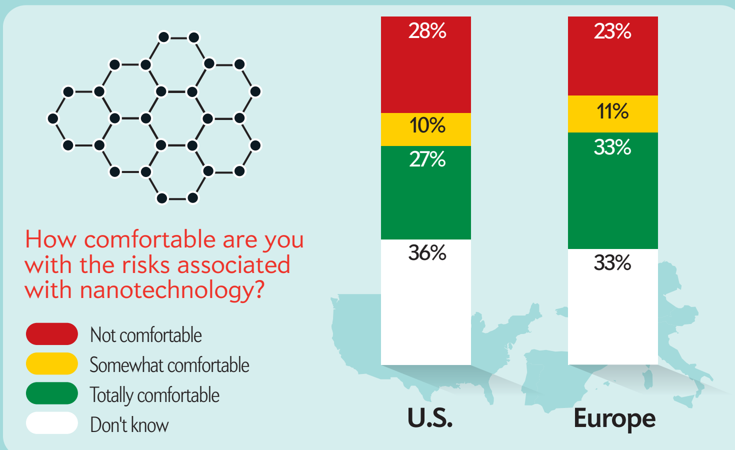


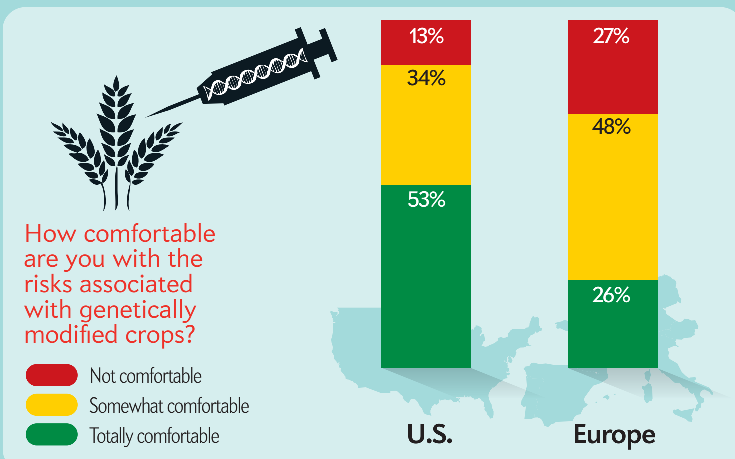
Further research on artificial organisms should not take place until it can be proven safe

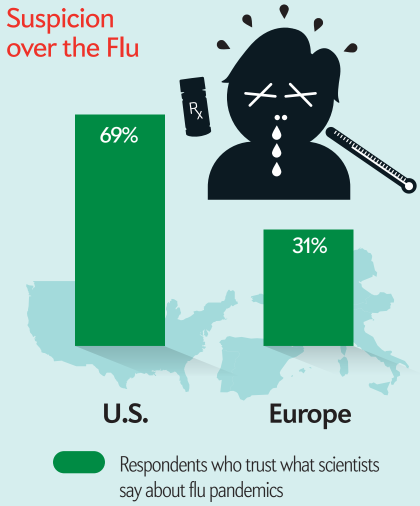
U.S. vs. Europe

Europeans and Americans differ sharply in their attitudes toward technology. Higher proportions of respondents from Europe worry about nuclear power and genetically modified crops than those from the U.S. (In this grouping, Europe includes Belgium, France, Germany, Italy and Spain, but not Britain, where opinion is more closely aligned with that of the U.S.) In both Europe and the U.S., nanotechnology seems to be a great unknown. Europeans also expressed a mistrust of what scientists have to say about flu pandemics [*see box at right*].









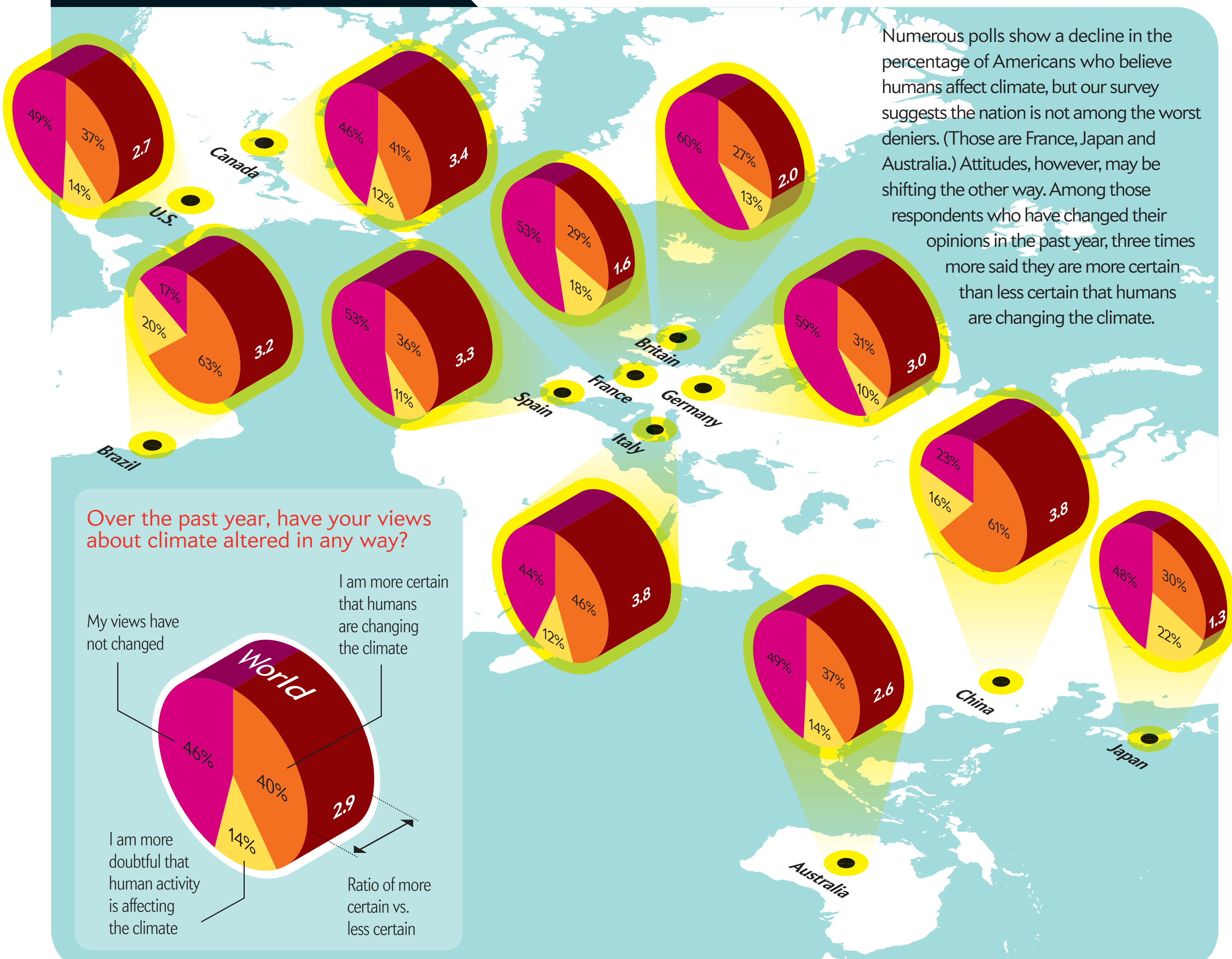
On June 11, 2009, the Geneva-based World Health Organization declared the H1N1 flu outbreak a pandemic, confirming what virologists already knew—that the flu virus had spread throughout the world. Governments called up billions of dollars' worth of vaccines and antiretroviral drugs, a medical arsenal that stood ready to combat a virus that, thankfully, turned out to be mild.

A year later two European studies charged that the WHO's decision-making process was tainted by conflicts of interest. In 2004 a WHO committee recommended that governments stockpile antiretroviral drugs in times of pandemic; the scientists on that committee were later found to have ties to drug companies. The WHO has refused to identify the scientists who sat on last year's committee that recommended the pandemic declaration, leading to suspicions that they might have ties to industry as well.

The controversy got a lot of press in Europe—the *Daily Mail,* a British tabloid, declared: "The pandemic that never was: Drug firms 'encouraged world health body to exaggerate swine flu threat'"; the controversy in the U.S. garnered little mention.

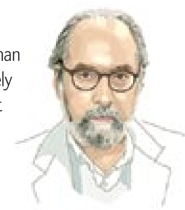
The brouhaha seems to have influenced opinion markedly in Europe. Nearly 70 percent of U.S. respondents in our survey trusted what scientists say about flu pandemics; in Europe, only 31 percent felt the same way. The figures represented the largest split between the U.S. and Europe on any issue in the poll.

Climate Denial on the Decline



Numerous polls show a decline in the percentage of Americans who believe humans affect climate, but our survey suggests the nation is not among the worst deniers. (Those are France, Japan and Australia.) Attitudes, however, may be shifting the other way. Among those respondents who have changed their opinions in the past year, three times more said they are more certain than less certain that humans are changing the climate.

Stephen S. Hall has been writing and reporting on the Human Genome Project for more than 20 years. He has written widely about contemporary science and is author of six books, most recently *Wisdom: From Philosophy to Neuroscience* (Knopf).



MEDICINE

Revolution Postponed

The Human Genome Project has failed so far to produce the medical miracles that scientists promised. Biologists are now divided over what, if anything, went wrong—and what needs to happen next

By Stephen S. Hall

A DECADE AGO BIOLOGISTS AND NONBIOLOGISTS alike gushed with optimism about the medical promise of the $3-billion Human Genome Project. In announcing the first rough draft of the human "book of life" at a White House ceremony in the summer of 2000, President Bill Clinton predicted that the genome project would "revolutionize the diagnosis, prevention and treatment of most, if not all, human diseases."

A year earlier Francis S. Collins, then head of the National Human Genome Research Institute and perhaps the project's most tireless enthusiast, painted a grand vision of the "personalized medicine" likely to emerge from the project by the year 2010: genetic tests indicating a person's risk for heart disease, cancer and other common maladies would be available, soon to be followed by preventives and therapies tailored to the individual.

Even before the first full sequence of DNA "letters" in human chromosomes was deciphered, a well-funded genomics juggernaut—armed with powerful sequencing and mapping technologies, burgeoning databases and a logical game to "mine miracles," as Collins put it, from the genome—set out to identify key genes underlying the great medical scourges of humankind.

Fast-forward to 2010, and the scientific community finds itself sobered and divided. The problem is not with the genome project itself, which has revolutionized the pace and scope of basic research, uncovered heretofore hidden purpose in what used to be called "junk DNA" and even detected traces of Neandertal DNA in our genomes. Cancer researcher Bert Vogelstein, echoing a widespread sentiment, says, "The Human Genome Project has radically changed the way we do science."

IN BRIEF

In the year 2000 leaders of the Human Genome Project announced completion of the first rough draft of the human genome. They predicted that follow-up research could pave the way to personalized medicine within as few as 10 years.

So far the work has yielded few medical applications, although the insights have revolutionized biology research.

Some leading geneticists argue that a key strategy for seeking medical insights into complex common diseases—known as the "common variant" hypothesis—is fundamentally flawed. Others say the strategy is valid, but more time is needed to achieve the expected payoffs.

Next-generation methods for studying the genome should soon help resolve the controversy and advance research into the genetic roots of major diseases.

SIRI STAFFORD *Getty Images*

The problem is that research springing from the genome project has failed as yet to deliver on the medical promises that Collins and others made a decade ago. Tumor biologist Robert A. Weinberg of the Whitehead Institute for Biomedical Research in Cambridge, Mass., says the returns on cancer genomics "have been relatively modest—*very* modest compared to the resources invested." Harold E. Varmus, former director of the National Institutes of Health, wrote recently in the *New England Journal of Medicine* that "only a handful of major changes … have entered routine medical practice"—most of them, he added, the result of "discoveries that preceded the unveiling of the human genome." Says David B. Goldstein, director of the Center for Human Genome Variation at Duke University: "It's fair to say that we're not going to be personalizing the treatment of common diseases next year."

Perhaps it was unreasonable to expect miracles in just 10 years (the predictions of genome project promoters notwithstanding). Behind today's disappointment, however, lies a more disturbing question: Does the surprisingly modest medical impact of the research so far indicate that scientists have been pursuing the wrong strategy for finding the genetic causes of common diseases? This strategy, at root, involves searching for slight variations in the DNA text of genes that could collectively increase an individual's risk of acquiring a common disorder. For years many scientists have pursued the hypothesis that certain common variants would be especially prevalent in people with particular illnesses and that finding those variants would lead to an understanding of how susceptibility to major, biologically complex diseases, such as type 2 diabetes and atherosclerosis, gets passed down from one generation to the next. Could the failure to find genetic variations with much effect on disease mean the "common variant" hypothesis is wrong?

This question has opened a fissure in the medical research community. On one side, leading genome scientists insist the common variant strategy is working. Recent research identifying genetic clues to disease has been "mind-blowing" over the past three years, says Eric S. Lander, director of the Broad Institute (an affiliate of the Whitehead Institute), and "we haven't even scratched the surface of common variants yet." He says the medical revolution will come as technologies improve—in time for our children if not for us. The revolution, in other words, is just running late.

On one side, leading genome scientists insist the "common variant" strategy for finding clues to the causes of common disorders is working.

Eric S. Lander of Broad Institute at M.I.T. calls recent progress "mind-blowing."

On the other side, a growing chorus of biologists has begun to insist that the common variant strategy is flawed. In a hotly debated essay this past April in *Cell,* geneticists Mary-Claire King and Jon M. McClellan of the University of Washington argued that "the vast majority of [common] variants have no established biological relevance to disease or clinical utility for prognosis or treatment." Geneticist Walter Bodmer, an elder statesman of British science, has flatly called the strategy of looking at common variants "scientifically wrong."

As some genome scientists celebrate the progress made so far, others who look at the same results see mostly failure and are now asking, Where do we go from here? The pursuit of an answer may take medical research down completely new avenues for understanding human disease and how it is passed down through the generations.

DISAPPOINTMENT

The common variant hypothesis seemed like a reasonable bet when it was first advanced in the 1990s, proposing that many familiar human maladies might be explained by the inheritance of a relatively small number of common gene variants. Genes have traditionally been defined as stretches of DNA that encode proteins. The variants might be thought of as slightly different, mutated texts of the same gene, altering either the protein-coding part of the DNA or the nearby DNA that regulates the rate and timing of gene "expression" (protein synthesis). Proteins carry out many tasks in cells, and deficiencies in their function or concentration can disrupt molecular pathways, or chains of interactions, important to health.

The belief that common variants would be helpful in understanding disease had a certain evolutionary logic. The rapid and recent population explosion of ancestral humans tens of thousands of years ago "locked" many variants in the human gene pool, Lander says. The bet was that these common variants ("common" usually meaning appearing in at least 5 percent of a given population) would be fairly easy to find and that a relatively small number of them (from several to perhaps dozens) would shape our susceptibility to hypertension, dementias and many other widespread disorders. The disease-related genetic variants and the proteins they encode, as well as the pathways in which they played crucial roles, could then become potential targets for drugs.

From the very beginning, however, the scheme was met with some dissent. In 1993 Kenneth M. Weiss, an evolutionary biologist at Pennsylvania State University, paraphrased Leo Tolstoy's famous line about families, from his novel *Anna Karenina,* to make a point about the genetics of complex diseases: "All healthy families resemble each other; each unhealthy family is unhealthy in its own way." The point, which Weiss and Columbia University statistical geneticist Joseph D. Terwilliger made repeatedly, was that common variants would probably have very small biological effects; if they did powerful harm, natural selection would have prevented them from becoming common in the population. Rather they argued that susceptibility to biologically complex diseases probably derives from inheritance of many *rare* disease-promoting variants that could number in the hundreds—perhaps thousands—in any given individual. In Tolstoy's idiom, ill people are genetically unhappy in their own way. Coming from a self-described "lunatic fringe," the argument didn't win many converts.

The obvious way to see who was right would have been to sequence the full genomes of diseased and healthy individuals and, using powerful computers, identify DNA variations that turned up in patients with the given disease but not in control subjects. In contrast to standard genetic research of the past, which relied on having a biology-based suspicion that a particular gene played

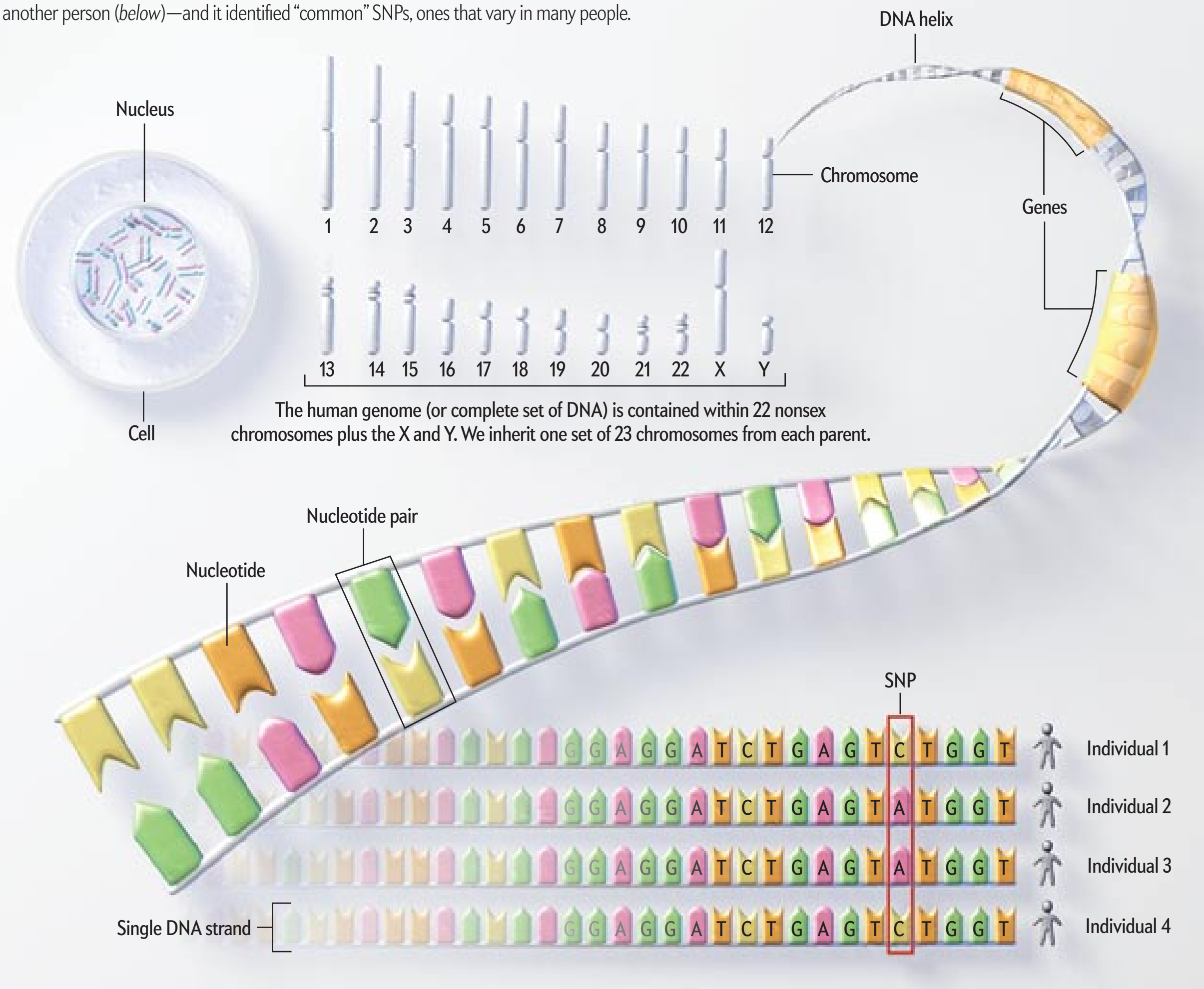
RICK FRIEDMAN *Corbis*

The Logic behind Genome Studies

Much research into the genetic contributions to common diseases has started with the seemingly logical assumption that DNA variants occurring frequently in the human population would be at fault. Some argue, though, that this reasoning is faulty.

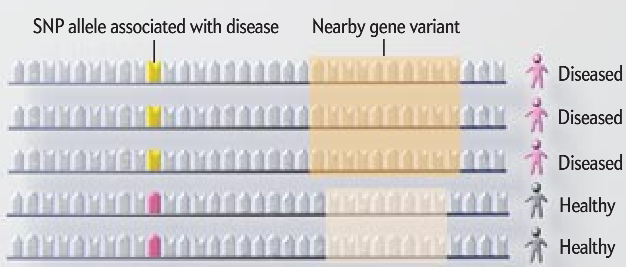
The Starting Point

The Human Genome Project identified the sequence of nucleotide pairs, or DNA building blocks, in the human genome, based on DNA from several volunteers. A single pair consists of a nucleotide (A, C, T or G) on one strand of the DNA double helix and its complement on the opposite strand (C always pairs with G; A with T). Related work revealed many single-nucleotide polymorphisms, or SNPs—chromosomal locations where a nucleotide pair in one person can differ from that in another person (*below*)—and it identified "common" SNPs, ones that vary in many people.



The Studies and Results

Investigators hoped that they could identify gene variants responsible for major diseases by comparing nucleotides at common SNPs throughout the genomes of people with and without a disease. SNP variants, or "alleles," and nearby protein-coding genes tend to be inherited together, and so researchers expected that SNP alleles occurring much more frequently in people with a disease would point to common gene variants important to the illness. These genome-wide association (GWA) studies uncovered many SNP alleles related to specific diseases. So far, though, the variations found have typically accounted for only a small fraction of disease risk.



Divergent Views

Among the most outspoken of the scientists arguing over the best way forward for finding the genetic bases of common complex diseases are Francis S. Collins (*top right*), head of the National Institutes of Health, who asserts that uncovering common gene variants associated with diseases is a powerful way to make medically valuable discoveries. Mary-Claire King (*bottom right*) of the University of Washington argues that seeking out rare genetic variants involved in disease makes more sense. She and others point to research by Helen H. Hobbs and Jonathan C. Cohen (*below*)—which looks for rare gene variants underlying extreme conditions—as a model for teasing out root causes of more common disorders. The work recently uncovered a major drug target for reducing heart disease risk in the general population.

JAMES D. WILSON *Getty Images* (*Collins*); COURTESY OF MARY-CLAIRE KING (*King*); COURTESY OF THE UNIVERSITY OF TEXAS SOUTHWESTERN MEDICAL CENTER AT DALLAS (*Hobbs and Cohen*)

a role in a disorder, such "agnostic" comparisons would presumably shine light on any and all DNA culprits, including those not previously suspected of being important. But 10 years ago it was technologically impossible to undertake such an approach, and the common variant hypothesis—if correct—offered a shortcut to discovering genes that contributed to common diseases.

Genome scientists guided by the common variant hypothesis began planning large-scale studies, known as genome-wide association studies (often called GWAS, or "gee-waz"), that relied on landmarks in DNA known as single-nucleotide polymorphisms, or SNPs (pronounced "snips"), to uncover common gene variants important in disease. SNPs, which occur throughout chromosomes, are sites in DNA (not necessarily within genes) where a single code letter in one person's DNA can differ from the letter at that same spot in another person's DNA. The plan was to examine large numbers of SNPs that often vary between people to see which versions occurred frequently in people with particular disorders. The SNPs statistically linked to disease would then lead researchers to nearby gene variants (inherited along with the landmarks) that could account for the association.

The plan, however, required the assembly of an atlas, as it were, of common human SNPs. Over the past decade or so biologists have gathered increasingly large numbers of SNPs to guide their search for the genetic roots of diseases, beginning in 1998 with the SNP Consortium (which assembled maps of these landmarks on each human chromosome) and progressing to the HapMap (which catalogued a larger swath of SNPs called a haplotype). In the past five years genome-wide association studies have looked at hundreds of thousands of common SNPs in the genomes of tens of thousands of individual patients and controls in the search for SNPs linked to common diseases.

This is where the rift in the biology community occurs. Lander and others hail the recent discovery of common, disease-associated SNPs as a portal to medically important pathways. To be sure, a flood of recent papers from huge genome consortiums have uncovered hundreds of common SNPs related to such diseases as schizophrenia, type 2 diabetes, Alzheimer's and hypertension. Francis Collins, in a recent appearance on PBS's *The Charlie Rose Show,* claimed scientists have "figured out" how almost 1,000 of those common gene variants "play a role in the risk of disease, and we have used that information already to change our entire view of how to develop new therapeutics for diabetes, for cancer, for heart disease." Others point out, however, that the data have not been very useful so far in predicting disease risk. In type 2 diabetes, for example, association studies analyzing 2.2 million SNPs in more than 10,000 people have identified 18 SNPs associated with the disease, yet these sites in total explain only 6 percent of the heritability of the disease—and almost none of the causal biology, according to Duke's Goldstein.

In 2008 Goldstein told the *New York Times:* "It's an astounding thing that we have cracked open the human genome and can look at the entire complement of common genetic variants,

and what do we find? Almost nothing. That is absolutely beyond belief." This past summer Goldstein spoke of the common variant/common disease hypothesis as a thing of the past: "We have entered and left that field, which explained less than a lot of people thought it would."

David Botstein of Princeton University offers much the same verdict on the strategy of creating a haplotype map: "It had to have been done. If it had not been tried, no one would have known that it didn't work." The $138-million HapMap, he says, was a "magnificent failure."

Walter Bodmer, who was among the first to propose the genome project in the 1980s and is a pioneer of the association studies that have dominated recent genomics, asserts that searching for common gene variants is a biological dead end. "It is almost impossible to find what the biological effects of these variant genes are, and that's absolutely key," he says. "The vast majority of [common] variants have shed no light on the biology of diseases."

NEW WAYS FORWARD

THE CURRENT ARGUMENT over the common variant hypothesis is not just an arcane scientific debate. It suggests at least one alternative way forward for solving what many are calling the "missing heritability" problem, at least for the short term. Bodmer, for instance, has been urging researchers to train their sights on rare genetic variants. The boundary where common ends and rare begins is not exact—"rare," by Bodmer's definition, refers to a particular genetic mutation that occurs in a range from 0.1 to 1 or 2 percent of the population (a frequency well below the resolution of most current genome-wide association studies). But the main idea of the hypothesis is that gene variants that have large disease-related effects tend to be rare, whereas those that are common almost always exert negligible or neutral effects.

This same argument surfaced in the controversial *Cell* essay, by King and McClellan, that this past spring stirred up so much animosity in the genome community—an essay Lander dismisses as an "opinion piece." King (who has found hundreds of rare variations in the *BRCA1* and *BRCA2* genes that cause familial breast cancer) and McClellan (who has similarly found many rare variants contributing to the genetics of schizophrenia) are suggesting a "new paradigm" for understanding complex diseases. They suggest that most of these diseases are "heterogeneous" (meaning that many different mutations in many different genes can produce the same disease), that most high-impact mutations are rare, and that many rare genetic variants are relatively recent additions to the gene pool. Rare variants identified in patients could thus lead researchers to specific molecular pathways related to a particular disease, and the biological understanding of those pathways could suggest new therapeutic interventions.

Bodmer, the *Cell* authors and others point to the work of Helen H. Hobbs and Jonathan C. Cohen as a model for using biology as a guide to uncovering medically significant information buried in the genome. The Hobbs-Cohen approach focuses on extreme cases of disease, assuming that rare gene variants that strongly perturb biology account for the extremity and will stand out starkly. They also pick and choose which genes to examine in those people, based on a knowledge of biology. And, they sequence specific candidate genes, looking for subtle but functionally dramatic variations between people, rather than using SNP associations, which can indicate the genetic neighborhood of a disease-related gene but often not the gene itself.

In 2000, when the big news in the genome field was the race between J. Craig Venter, founder of the biotech company Celera Genomics, and NIH scientists to produce the first rough draft of the human genome sequence, Hobbs and Cohen quietly embarked on a project known as the Dallas Heart Study to help uncover the causes of heart disease. Cohen, a South African physiologist, had studied cholesterol metabolism (its synthesis and breakdown) for many years. Hobbs, trained as an M.D. and now a Howard Hughes Medical Institute investigator at the University of Texas Southwestern Medical Center at Dallas, had done research in the laboratory of Michael S. Brown and Joseph L. Goldstein, who shared a Nobel Prize in 1985 for their work on cholesterol metabolism, which in turn laid the groundwork for the development of the popular class of cholesterol-lowering drugs known as statins.

Hobbs and Cohen set their scientific compass according to a biological "intuition" that represented a strategy completely different from almost everyone else working in genomics. They recruited some 3,500 residents of Dallas County (half of them African-Americans) and then gave them intensive medical workups. They did not just focus on the genome (although they dutifully collected everyone's DNA) but gathered very precise measures for many factors that can contribute to coronary artery disease: blood chemistry (including cholesterol numbers), metabolism, body fat, cardiac function, arterial thickening (assessed through high-tech imaging) and environmental influences. Over the course of two years they compiled a massive, highly detailed database of individual physical traits—what geneticists call "phenotypes."

The current argument over the common variant hypothesis suggests at least one way forward for solving what many are calling the "missing heritability" problem.

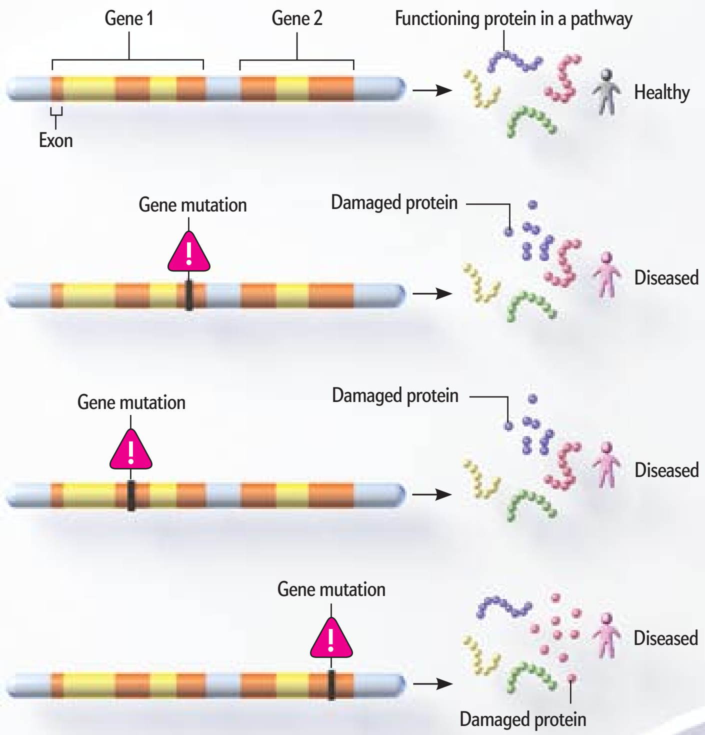
After that, they concentrated their genomic attention on people with particularly dramatic phenotypes—specifically with extremely high or low numbers for high-density lipoproteins (HDL, often called the "good" cholesterol) or for low-density lipoproteins (LDL, the "bad" cholesterol). And there was nothing agnostic about their search through the genome. As Cohen puts it, "We came at this from a more functional standpoint."

As they reported in *Science* in 2004, they first looked at patients with very low HDL concentrations in the blood, a condition that increases risk for heart disease. They knew of three genes involved in rare disorders of cholesterol metabolism, and so they compared DNA sequences from those genes in the very low HDL patients and people with high HDL levels, finding several rare variants linked to the extremely depressed HDL levels. They also reported that mutations in the affected genes "contribute significantly" to low HDL values in the general population.

In 2005 Hobbs and Cohen turned their attention to people in the Dallas Heart Study who were found to have unusually low LDL levels. The researchers hit a genomic jackpot when they analyzed the DNA sequences of a gene called *PCSK9*, known to

What Now?

A number of scientists searching for the heritable influences on common diseases are pushing for research strategies that do not rely on massive statistical analyses of common SNPs, which, some argue, are not likely to be extremely informative about disease risk.

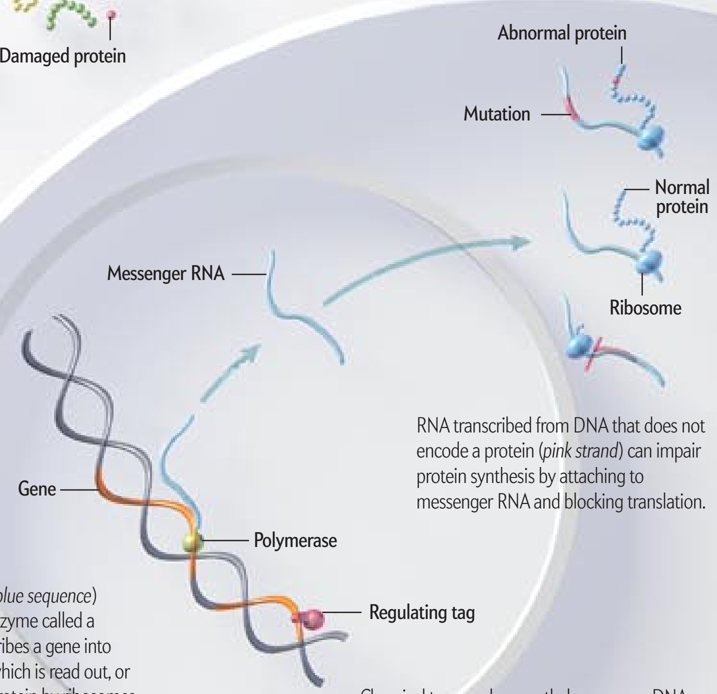


Search for Rare Gene Variants

Some researchers say that rare mutations in genes probably contribute more to disease than do the gene variants linked to common SNPs. Even if each person is ill because of a unique rare mutation, it is possible that many of those mutations affect genes whose encoded proteins work together (operate in the same "pathway") to accomplish some important job in the body. Identifying the affected genes should suggest ways to compensate for a pathway's disruption. One way to find important rare mutations is to fully sequence and compare all the protein-coding bits (exons) in the genes of diseased and healthy people (*left*). This approach, known as exome sequencing, is already under way in a number of labs.

Look beyond Genes

SNP studies and the search for rare variants focus on finding variations in the DNA sequences of protein-coding genes and thus in proteins involved in disease (*top right*). But other processes not involving changes in those sequences can also impair the manufacture of needed proteins and thereby predispose people to illnesses. Two of those are depicted here schematically (*bottom right*). Investigators are devising ways to examine those processes as well.



RNA transcribed from DNA that does not encode a protein (*pink strand*) can impair protein synthesis by attaching to messenger RNA and blocking translation.

Protein synthesis (*blue sequence*) occurs when an enzyme called a polymerase transcribes a gene into messenger RNA, which is read out, or translated, into a protein by ribosomes. If a mutant version of the gene is transcribed into RNA, the resulting protein will also be abnormal.

Chemical tags, such as methyl groups, on DNA can decrease or increase transcription. These tags can pass from generation to generation in germ cells and may influence disease susceptibility.

Illustration by Bryan Christie

be involved in cholesterol metabolism. Two mutations that silenced the gene correlated with the low LDL levels. In a follow-up study that analyzed data collected from populations in Mississippi, North Carolina, Minnesota and Maryland over a 15-year period, Hobbs and Cohen determined that African-Americans with one or another silencing mutation in *PCSK9* have a 28 percent reduction in LDL levels and an astounding 88 percent reduction in the risk of coronary heart disease. In whites, a mutation in the same gene reduced LDL by 15 percent and reduced the risk of heart disease by 47 percent. Hardly any of the hundreds of genome-wide association studies have identified genes with such a large effect on disease risk.

Drug companies are already testing molecules that shut off the *PCSK9* gene, or perturb the molecular pathway the gene affects, as a way to lower LDL and reduce the risk of heart disease in the general population. *PCSK9,* Hobbs says, is a "top-10 target" of virtually every pharmaceutical company now.

Acknowledging the small effect of genes identified by the common variant approach and heartened by the success of the Hobbs-Cohen work, David Goldstein and Elizabeth T. Cirulli, also at Duke, recently proposed expanding the search for medically important rare variants. One idea, for example, is to sequence and compare whole "exomes" in carefully selected people. The exome is a collection of actual protein-coding parts of genes (exons) in chromosomes, along with nearby regions that regulate gene activity; it does not include the stretches of DNA that lie between exons or genes. Cirulli and Goldstein also suggest looking for these rare variants within families affected by a common disease or in people who share an extreme trait, where significant DNA differences can more easily be identified. This work is already under way in many labs. "We are sequencing exomes in the lab every day," University of Washington's King says. Exome sequencing is a stop-gap strategy, though, until inexpensive, reliable whole-genome sequencing becomes available, probably in three to five years.

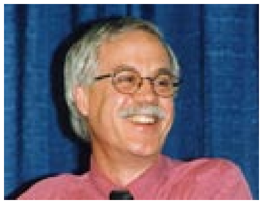
BEWARE THE RABBIT HOLE

A FEW BRAVE VOICES ARE suggesting that the rabbit's hole of human biology may go still deeper than a focus on DNA sequences and proteins can reveal. Traditional genetics, they say, may not capture the molecular complexity of genes and their role in disease. The vast areas of DNA that do not code for proteins, once dismissed as "junk," are now known to conceal important regulatory regions. Some DNA stretches produce small bits of RNA that can interfere with gene expression, for instance. And chemical "tags" on DNA that do not change its sequence—that are thus "epigenetic"—can also influence gene expression and can be modified by environmental factors over the course of a lifetime. This environmentally modified DNA may even be passed on to offspring.

Put simply, the very definition of a gene—not to mention a medically significant gene—is now vexed by multiple layers of complexity. What was once assumed to be a straightforward, one-way, point-to-point relation between genes and traits has now become the "genotype-phenotype problem," where knowing the protein-coding sequence of DNA tells only part of how a trait comes to be.

In animal experiments, Joseph H. Nadeau, director of scientific development at the Institute for Systems Biology in Seattle, has tracked more than 100 biochemical, physiological and behavioral traits that are affected by epigenetic changes and has seen some of these changes passed down through four generations. "It's *totally* Lamarckian!" he laughs, referring to the 18th-century biologist Jean-Baptiste Lamarck's idea that acquired traits could be inherited.

Put simply, the very definition of a gene—not to mention a medically significant gene—is now vexed with multiple layers of complexity.



COURTESY OF JOSEPH H. NADEAU

Joseph H. Nadeau has documented inheritance of acquired characteristics in mice.

As if that level of complexity were not enough, Nadeau has experimental evidence that the function of one particular gene sometimes depends on the specific constellation of genetic variants surrounding it—an ensemble effect that introduces a contextual, postmodern wrinkle to genetic explanations of disease. It suggests, Nadeau says, that some common illnesses may ultimately be traceable to a very large number of genes in a network or pathway whose effects may each vary depending on the gene variants a person has; the presence of one gene variant, say, can exacerbate or counteract the effect of another disease-related gene in the group. "My guess is that this unconventional kind of inheritance is going to be more common than we would have expected," Nadeau says.

Exactly how powerful the aspects Nadeau addresses will turn out to be in disease remains unclear. In the meantime, a new generation of fast, cheap sequencing technologies will soon allow biologists to compare entire genomes, by which time the common versus rare variant debate may subside into ancient history. Far from casting a pall over the field, the current puzzle over missing heritability has even a common variant skeptic such as King excited about the next few years. "Now we have the tools to address these questions properly," she says. "Imagine what Darwin and Mendel could do with this technology. It is a fabulous time to be doing genomics." This time around, however, no one is predicting a timetable for medical miracles. SA

MORE TO EXPLORE

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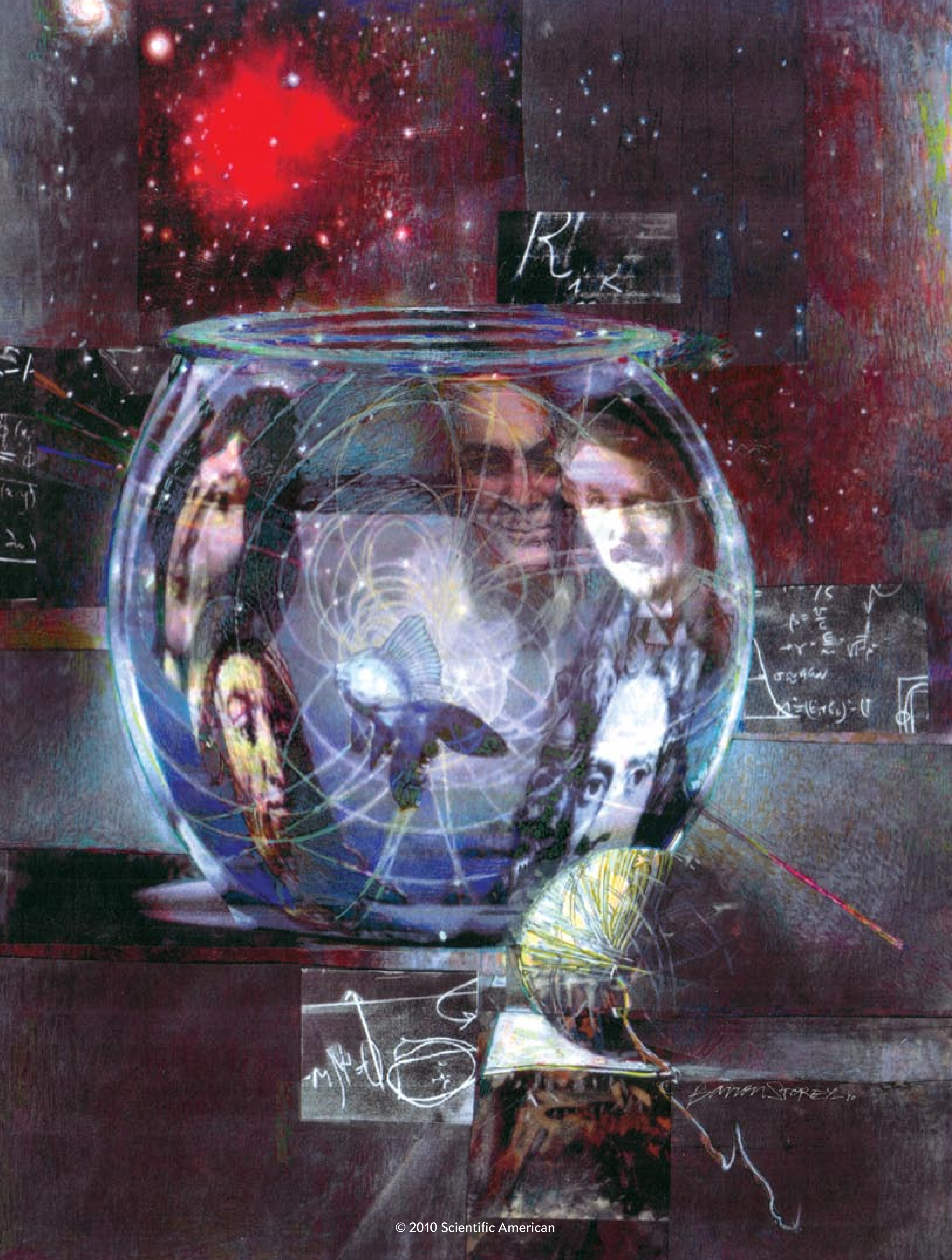

Stephen Hawking's work laid the foundation for the modern understanding of black holes and the origin of the universe, although, as he has pointed out, he is at least as famous for his appearances on *The Simpsons* and *Star Trek: The Next Generation*. From 1979 to last year, he was Lucasian Professor of Mathematics at the University of Cambridge, the post once held by Isaac Newton. His books include the classic *A Brief History of Time*, which has sold more than nine million copies.

Leonard Mlodinow is a theoretical physicist at the California Institute of Technology. He has authored seven books—including *Euclid's Window: The Story of Geometry from Parallel Lines to Hyperspace* and *The Drunkard's Walk: How Randomness Rules Our Lives*—as well as scripts for *MacGyver* and *Star Trek: The Next Generation*.

PHYSICS

The (Elusive) Theory of Everything

Physicists have long sought to find one final theory that would unify all of physics. Instead they may have to settle for several

By Stephen Hawking and Leonard Mlodinow

IN BRIEF

Stephen Hawking's work on black holes and the origin of the universe is arguably the most concrete progress theoretical physicists have made toward reconciling Einstein's gravitation and quantum physics into one final theory of everything.

Physicists have a favorite candidate for such a theory, string theory, but it comes in five different formulations, each covering a restricted range of situations.

A network of mathematical connections, however, links the different string theories into one overarching system, enigmatically called M-theory: perhaps the network is itself the final theory.

In a new book, *The Grand Design*, Hawking and Caltech physicist Leonard Mlodinow argue that the quest to discover a final theory may in fact never lead to a unique set of equations. Every scientific theory, they write, comes with its own model of reality, and it may not make sense to talk of what reality actually is. This essay is based on that book.

Illustrations by Barron Storey

A FEW YEARS AGO THE CITY COUNCIL OF MONZA, Italy, barred pet owners from keeping goldfish in curved fishbowls. The sponsors of the measure explained that it is cruel to keep a fish in a bowl because the curved sides give the fish a distorted view of reality. Aside from the measure's significance to the poor goldfish, the story raises an interesting philosophical question: How do we know that the reality we perceive is true? The goldfish is seeing a version of reality that is different from ours, but can we be sure it is any less real? For all we know, we, too, may spend our entire lives staring out at the world through a distorting lens.

In physics, the question is not academic. Indeed, physicists and cosmologists are finding themselves in a similar predicament to the goldfish's. For decades we have strived to come up with an ultimate theory of everything—one complete and consistent set of fundamental laws of nature that explain every aspect of reality. It now appears that this quest may yield not a single theory but a family of interconnected theories, each describing its own version of reality, as if it viewed the universe through its own fishbowl.

This notion may be difficult for many people, including some working scientists, to accept. Most people believe that there is an objective reality out there and that our senses and our science directly convey information about the material world. Classical science is based on the belief that an external world exists whose properties are definite and independent of the observer who perceives them. In philosophy, that belief is called realism.

Those who remember Timothy Leary and the 1960s, however, know of another possibility: one's concept of reality can depend on the mind of the perceiver. That viewpoint, with various subtle differences, goes by names such as antirealism, instrumentalism or idealism. According to those doctrines, the world we know is constructed by the human mind employing sensory data as its raw material and is shaped by the interpretive structure of our brains. This viewpoint may be hard to accept, but it is not difficult to understand. There is no way to remove the observer—us—from our perception of the world.

The way physics has been going, realism is becoming difficult to defend. In classical physics—the physics of Newton that so accurately describes our everyday experience—the interpretation of terms such as object and position is for the most part in harmony with our commonsense, "realistic" understanding of those concepts. As measuring devices, however, we are crude instruments. Physicists have found that everyday objects and the light we see them by are made from objects—such as electrons and photons—that we do not perceive directly. These objects are governed not by classical physics but by the laws of quantum theory.

The reality of quantum theory is a radical departure from that of classical physics. In the framework of quantum theory, particles have neither definite positions nor definite velocities unless and until an observer measures those quantities. In some cases, individual objects do not even have an independent existence but rather exist only as part of an ensemble of many. Quantum physics also has important implications for our concept of the past. In classical physics, the past is assumed to exist as a definite series of events, but according to quantum physics, the past, like the future, is indefinite and exists only as a spectrum of possibilities. Even the universe as a whole has no single past or history. So quantum physics implies a different reality than that of classical physics—even though the latter is consistent with our intuition and still serves us well when we design things such as buildings and bridges.

These examples bring us to a conclusion that provides an important framework with which to interpret modern science. In our view, there is no picture- or theory-independent concept of reality. Instead we adopt a view that we call model-dependent realism: the idea that a physical theory or world picture is a model (generally of a mathematical nature) and a set of rules that connect the elements of the model to observations. According to model-dependent realism, it is pointless to ask whether a model is real, only whether it agrees with observation. If two models agree with observation, neither one can be considered more real than the other. A person can use whichever model is more convenient in the situation under consideration.

DO NOT ATTEMPT TO ADJUST THE PICTURE

THE IDEA OF ALTERNATIVE REALITIES is a mainstay of today's popular culture. For example, in the science-fiction film *The Matrix* the human race is unknowingly living in a simulated virtual reality created by intelligent computers to keep them pacified and content while the computers suck their bioelectrical energy (whatever that is). How do we know we are not just computer-generated characters living in a Matrix-like world? If we lived in a synthetic, imaginary world, events would not necessarily have any logic or consistency or obey any laws. The aliens in control might find it more interesting or amusing to see our reactions, for example, if everyone in the world suddenly decided that chocolate was repulsive or that war was not an option, but that has never happened. If the aliens did enforce consistent laws, we would have no way to tell that another reality stood behind the simulated one. It is easy to call the world the aliens live in the "real" one and the computer-generated world a false one. But if—like us—the beings in the simulated world could not gaze into their universe from the outside, they would have no reason to doubt their own pictures of reality.

The goldfish are in a similar situation. Their view is not the same as ours from outside their curved bowl, but they could still formulate scientific laws governing the motion of the objects they observe on the outside. For instance, because light bends as it travels from air to water, a freely moving object that we would observe to move in a straight line would be observed by the goldfish to move along a curved path. The goldfish could formulate scientific laws from their distorted frame of reference that would always hold true and that would enable them to make predictions about the future motion of objects outside the bowl. Their laws would be more complicated than the laws in our frame, but simplicity is a matter of taste. If the goldfish formulated such a theory, we would have to admit the goldfish's view as a valid picture of reality.

A famous real-world example of different pictures of reality is the contrast between Ptolemy's Earth-centered model of the cosmos and Copernicus's sun-centered model. Although it is not uncommon for people to say that Copernicus proved Ptolemy wrong, that is not true. As in the case of our view versus that of the goldfish, one can use either picture as a model of the universe, because we can explain our observations of the heavens by assuming either Earth or the sun to be at rest. Despite its role in philosophical debates over the nature of our universe, the real advantage of the Copernican system is that the equations of motion are much simpler in the frame of reference in which the sun is at rest.

Model-dependent realism applies not only to scientific models but also to the conscious and subconscious mental models we all create to interpret and understand the everyday world. For example, the human brain processes crude data from the optic nerve, combining input from both eyes, enhancing the resolution and filling in gaps such as the one in the retina's blind spot. Moreover, it creates the impression of three-dimensional space from the retina's two-dimensional data. When you see a chair, you have merely used the light scattered by the chair to build a mental image or model of the chair. The brain is so good at model-building that if people are fitted with glasses that turn the images in their eyes upside down, their brains change the model so that they again see things the right way up—hopefully before they try to sit down.

GLIMPSES OF THE DEEP THEORY

IN THE QUEST TO DISCOVER the ultimate laws of physics, no approach has raised higher hopes—or more controversy—than string theory. String theory was first proposed in the 1970s as an attempt to unify all the forces of nature into one coherent framework and, in particular, to bring the force of gravity into the domain of quantum physics. By the early 1990s, however, physicists discovered that string theory suffers from an awkward issue: there are five different string theories. For those advocating that string theory was the unique theory of everything, this was quite an embarrassment. In the mid-1990s researchers started discovering that these different theories—and yet another theory called supergravity—actually describe the same phenomena, giving them some hope that they would amount eventually to a unified theory. The theories are indeed related by what physicists call dualities, which are a kind of mathematical dictionaries for translating concepts back and forth. But, alas, each theory is a good description of phenomena only under a certain range of conditions—for example, at low energies. None can describe every aspect of the universe.

String theorists are now convinced that the five different string theories are just different approximations to a more fundamental theory called M-theory. (No one seems to know what the "M" stands for. It may be "master," "miracle" or "mystery," or all three.) People are still trying to decipher the nature of M-theory, but it seems that the traditional expectation of a single theory of nature may be untenable and that to describe the universe we must employ different theories in different situations. Thus, M-theory is not a theory in the usual sense but a network of theories. It is a bit like a map. To faithfully represent the entire Earth on a flat surface, one has to use a collection of maps, each of which covers a limited region. The maps overlap one another, and where they do, they show the same landscape. Similarly, the different theories in the M-theory family may look very different, but they can all be regarded as versions of the same underlying theory, and they all predict the same phenomena where they overlap, but none works well in all situations.

Whenever we develop a model of the world and find it to be successful, we tend to attribute to the model the quality of reality or absolute truth. But M-theory, like the goldfish example, shows that the same physical situation can be modeled in different ways, each employing different fundamental elements and concepts. It might be that to describe the universe we have to employ different theories in different situations. Each theory may have its own version of reality, but according to model-dependent realism, that diversity is acceptable, and none of the versions can be said to be more real than any other. It is not the physicist's traditional expectation for a theory of nature, nor does it correspond to our everyday idea of reality. But it might be the way of the universe. SA

MORE TO EXPLORE

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COMMENT ON THIS ARTICLE **www.ScientificAmerican.com/oct2010**

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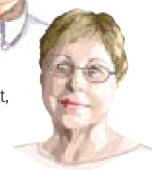
Susan Leigh Anderson received her Ph.D. from the University of California, Los Angeles, and is professor emeritus of philosophy at the University of Connecticut, specializing in applied ethics. In 2005 she and Michael Anderson helped to organize the first international symposium on machine ethics. They have a book on machine ethics forthcoming from Cambridge University Press.



ROBOTICS

ROBOT BE GOOD

Autonomous machines will soon play a big role in our lives. It's time they learned how to behave ethically

By Michael Anderson and Susan Leigh Anderson

IN BRIEF

Robots that make autonomous decisions, such as those being designed to assist the elderly, may face ethical dilemmas even in seemingly everyday situations.

One way to ensure ethical behavior in robots that interact with humans is to program general ethical principles into them and let them use those principles to make decisions on a case-by-case basis.

Artificial-intelligence techniques can produce the principles themselves by abstracting them from specific cases of ethically acceptable behavior using logic.

The authors have followed this approach and for the first time programmed a robot to act based on an ethical principle.

Nao, manufactured by Aldebaran Robotics, is the first robot to have been programmed with an ethical principle.

Photograph by Darren Braun

IN THE CLASSIC NIGHTMARE SCENARIO OF DYSTOPIAN SCIENCE FICTION, machines become smart enough to challenge humans—and they have no moral qualms about harming, or even destroying, us. Today's robots, of course, are usually developed to help people. But it turns out that they face a host of ethical quandaries that push the boundaries of artificial intelligence, or AI, even in quite ordinary situations.

Imagine being a resident in an assisted-living facility—a setting where robots will probably become commonplace soon. It is almost 11 o'clock one morning, and you ask the robot assistant in the dayroom for the remote so you can turn on the TV and watch *The View*. But another resident also wants the remote because she wants to watch *The Price Is Right*. The robot decides to hand the remote to her. At first, you are upset. But the decision, the robot explains, was fair because you got to watch your favorite morning show the day before. This anecdote is an example of an ordinary act of ethical decision making, but for a machine, it is a surprisingly tough feat to pull off.

The scenario we just described is still theoretical, but we already have created a first demonstration of a robot able to make similar decisions. We have endowed our machine with an ethical principle that it uses to determine how often to remind a patient to take a medication. Our robot's programming so far is capable of choosing among only a few possible options, such as whether to keep reminding a patient to take medicine, and when to do so, or to accept the patient's decision not to take the medication. But to our knowledge, it is the first robot to rely on an ethical principle to determine its actions.

It would be extremely difficult, if not impossible, to anticipate every decision a robot might ever face and program it so that it will behave in the desired manner in each conceivable situation. On the other hand, preventing robots from taking absolutely any action that might raise ethical concerns could unnecessarily limit opportunities for robots to perform tasks that could greatly improve human lives. We believe that the solution is to design robots able to apply ethical principles to new and unanticipated situations—say, to determining who gets to read a new book, rather than who next gets control of the remote. This approach has the additional benefit of enabling robots to refer to those principles if asked to justify their behavior, which is essential if humans are to feel comfortable interacting with them. As a side benefit, efforts to design ethical robots could also lead to progress in the field of ethics itself, by forcing philosophers to examine real-life situations. As Tufts University philosopher Daniel C. Dennett recently put it, "AI makes philosophy honest."

I, ROBOT

AUTONOMOUS ROBOTS ARE LIKELY to soon be a part of our daily lives. Some airplanes are already capable of flying themselves, and self-driving cars are at the development stage. Even "smart homes," with computers controlling everything from lighting to the A/C, can be thought of as robots whose body is the entire home—just as HAL 9000, the computer in Stanley Kubrick's classic *2001: A Space Odyssey,* was the brains of a robot spaceship. And several companies have been developing robots that can assist the elderly with everyday tasks, either to supplement the staff of an assisted-living facility or to help the aged live at home by themselves. Although most of these robots do not have to make life-or-death decisions, for them to be welcome among us their actions should be perceived as fair, correct or simply kind. Their inventors, then, had better take the ethical ramifications of their programming into account.

If one agrees that embodying ethical principles in autonomous machines is key to their success in interacting with humans, then the first question becomes, Which principles should go in them? Fans of science-fiction literature may believe that Isaac Asimov already provided the answer some time ago, with his original Three Laws of Robotics:

1. A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

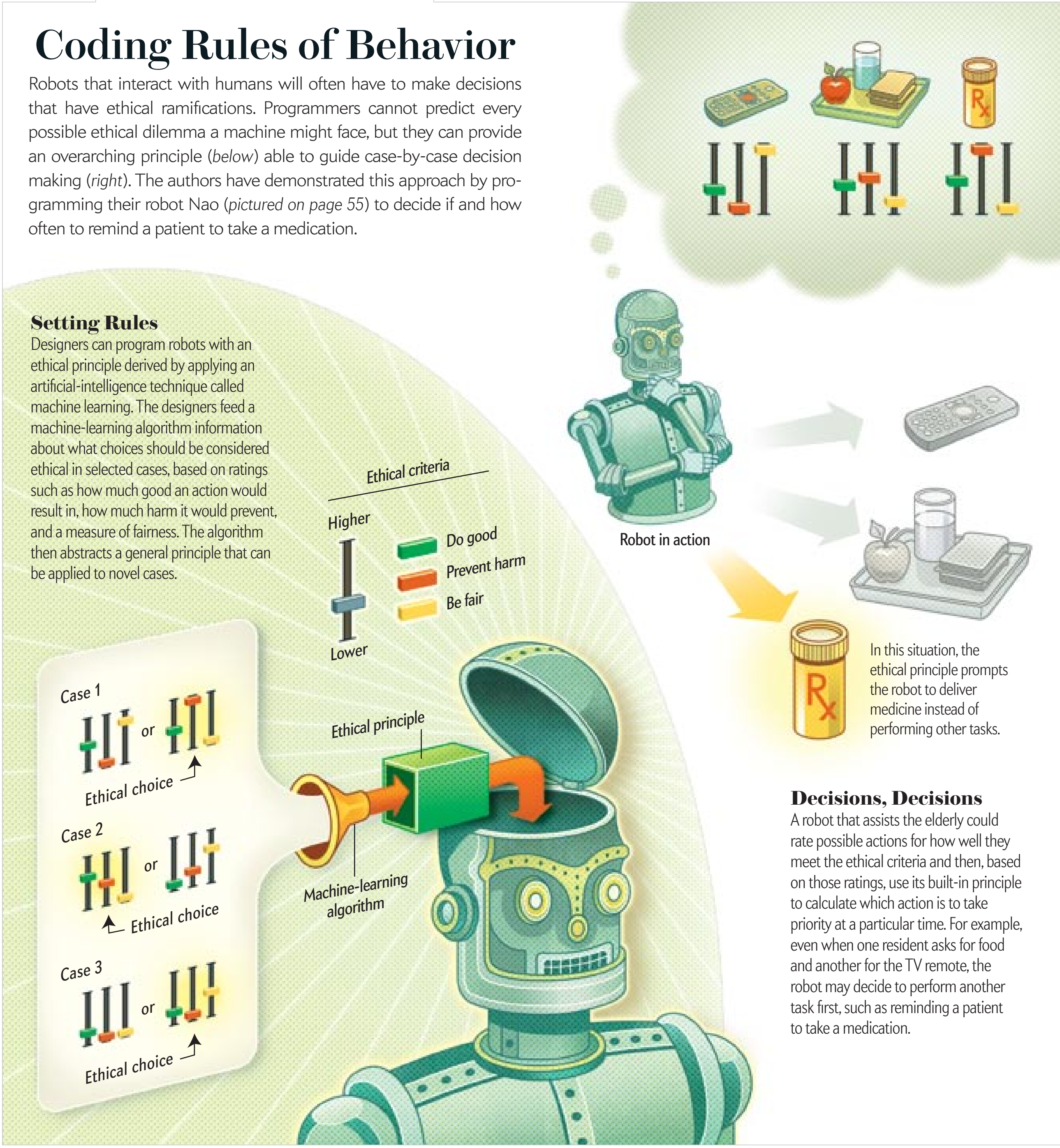
But some have discovered inconsistencies when thinking through the implications of these laws, which Asimov first articulated in a short story in 1942. And Asimov himself illustrated how unsuitable they were in his 1976 story *The Bicentennial Man,* in which human bullies order a robot to dismantle himself. The robot has to obey the bullies because of the Second Law, and he cannot defend himself without harming them, which would be a violation of the First Law.

If Asimov's laws are not acceptable, what is the alternative? Is an alternative even possible? Some people believe that implementing ethical behavior in machines is a hopeless proposition. Ethics, they say, is not the sort of thing that can be computed, and so it will be impossible to program it into a machine. Already in the 19th century, however, English philosophers Jeremy Bentham and John Stuart Mill maintained that ethical decision making is a matter of performing "moral arithmetic." Their doctrine of Hedonistic Act Utilitarianism, formulated in opposition to an ethic based on subjective intuition, holds that the right action is the one likely to result in the greatest "net pleasure," calculated by adding up units of pleasure and subtracting units of displeasure experienced by all those affected. Most ethicists doubt this theory accounts for all the dimensions of ethical concern. For example, it has difficulty capturing justice considerations and can lead to an individual being sacrificed in the interests of the majority. But at least it demonstrates that a plausible ethical theory is, in principle, computable.

Others doubt that machines will ever be capable of making ethical decisions, because machines lack emotions and so cannot appreciate the feelings of all those who might be affected by their actions. But humans are so prone to getting carried away by emotions that they often end up behaving unethically. This quality of ours, as well as our tendency to favor ourselves and those near and dear to us, often makes us less than ideal ethical decision makers. We think it is very possible that a properly

Coding Rules of Behavior

Robots that interact with humans will often have to make decisions that have ethical ramifications. Programmers cannot predict every possible ethical dilemma a machine might face, but they can provide an overarching principle (*below*) able to guide case-by-case decision making (*right*). The authors have demonstrated this approach by programming their robot Nao (*pictured on page 55*) to decide if and how often to remind a patient to take a medication.



Setting Rules
Designers can program robots with an ethical principle derived by applying an artificial-intelligence technique called machine learning. The designers feed a machine-learning algorithm information about what choices should be considered ethical in selected cases, based on ratings such as how much good an action would result in, how much harm it would prevent, and a measure of fairness. The algorithm then abstracts a general principle that can be applied to novel cases.

Decisions, Decisions
A robot that assists the elderly could rate possible actions for how well they meet the ethical criteria and then, based on those ratings, use its built-in principle to calculate which action is to take priority at a particular time. For example, even when one resident asks for food and another for the TV remote, the robot may decide to perform another task first, such as reminding a patient to take a medication.

trained machine could be designed to be impartial and to perceive human emotions and include them in its calculations, even if it does not have emotions itself.

LEARNING BY EXAMPLE

ASSUMING THAT IT IS POSSIBLE to give ethical rules to robots, whose ethical rules should those be? After all, no one has yet been able to put forward a general set of ethical principles for real-live humans that is accepted universally. But machines are typically created to function in specific, limited domains. Determining ethical parameters for behavior in such cases is a less daunting task than trying to devise universal rules of ethical and unethical behavior, which is what ethical theorists attempt to do. Moreover, when given the description of a particular situation within many contexts in which robots are likely to function, most ethicists would agree on what is ethically permissible and what is not. (In situations in which there is no such agreement, we believe that machines should not be allowed to make autonomous decisions at all.)

Researchers have proposed various different approaches to deriving rules for machine behavior, usually by means of AI techniques. For example, in 2005 Rafal Rzepka and Kenji Araki

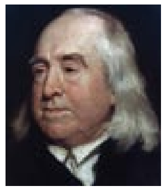
Illustration by Peter and Maria Hoey

NOTABLE MOMENTS IN MACHINE ETHICS

When Science Imitates Art

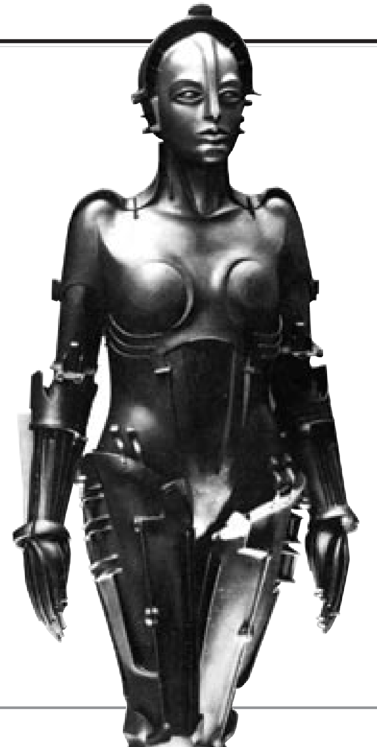
Long before ethicists, roboticists and AI experts became interested in the possible ethical ramifications of robots' behavior, science-fiction writers and film directors toyed with scenarios that were not always unrealistic. In recent years, however, machine ethics has become a bona fide field of research, in part drawing inspiration from the writings of 18th-century philosophers.

← **1495** Leonardo da Vinci designs one of the first humanoid robots



1780s Jeremy Bentham (*above*) and John Stuart Mill propose that ethics is computable

1921 Karel Čapek's play *R.U.R* first introduces the word "robot" and the concept of robot rebellion



1750 1800 1850

of Hokkaido University in Japan proposed "democracy-dependent algorithms" that would mine the Web for information on what people have in the past considered ethically acceptable actions and then use statistical analysis to produce answers to new questions. In 2006 Marcello Guarini of the University of Windsor in Ontario suggested that neural networks—algorithms inspired by the human brain that learn how to process information in an increasingly optimal way—could be "trained" using existing cases to recognize and select what are ethically acceptable decisions in similar cases.

In our view, reflected in our research, ethical decision making involves balancing several obligations, what ethicists refer to as prima facie duties (*prima facie* is Latin for "at first sight"). These are duties we should basically try to adhere to, each of which, however, can be overridden on occasion by one of the other duties. For example, people should generally try to keep their promises, but if they could prevent much harm by breaking a trivial promise, they should do so. When duties are in conflict with one another, ethical principles can determine which one should take precedence in each particular situation.

To obtain ethical principles that can be programmed into a robot, we employ an AI technique called machine learning. Our algorithm accesses a representative number of particular cases in which humans have determined certain decisions to be ethically correct. Then, using inductive logic, it abstracts an ethical principle. This "learning" stage takes place at the time of software design, and the resulting ethical principle is then encoded into the robot's programming.

As a first test of our method, we considered a scenario in which the robot has to remind a patient to take a medication and notify an overseer when the patient does not comply. The robot must balance three duties: ensuring that the patient receives a possible benefit from taking the medication; preventing the harm that might result from not taking the medication; and respecting the autonomy of the patient (who is assumed to be adult and competent). Respecting patient autonomy, in particular, is considered a high priority in the field of medical ethics; this duty could be violated if the robot reminds the patient too often or notifies the overseer too soon for noncompliance.

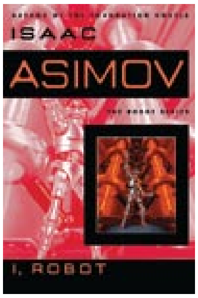
After we fed it information about particular cases, the machine-learning algorithm produced the following ethical principle: a health care robot should challenge a patient's decision—violating the patient's autonomy—whenever doing otherwise would fail to prevent harm or severely violate the duty of promoting patient welfare.

AN IDEA WITH LEGS

WE THEN PROGRAMMED the principle into a humanoid robot, Nao, developed by the French company Aldebaran Robotics. Nao is capable of finding and walking toward a patient who needs to be reminded to take a medication, bringing the medication to the patient, interacting using natural language, and notifying an overseer by e-mail when necessary. The robot receives initial input from the overseer (who typically would be a physician), including: what time to take a medication, the maximum amount of harm that could occur if this medication is not taken, how long it would take for this maximum harm to occur, the maximum amount of expected good to be derived from taking this medication, and how long it would take for this benefit to be lost. From this input, the robot calculates its levels of duty satisfaction or violation for each of the three duties and takes different actions depending on how those levels change over

COURTESY OF NICCOLAI-TEKNOART/MUSEUM OF LEONARDO DA VINCI, FLORENCE (*humanoid robot*); THE GRANGER COLLECTION (*Bentham*); GETTY IMAGES (*R.U.R. poster*); UFA/THE KOBAL COLLECTION (Metropolis *robot*)

1927 The "Maschinenmensch" in Fritz Lang's silent film *Metropolis* (*left*) is instructed to harm humans



1942 Isaac Asimov's *I, Robot* spells out his Three Laws of Robotics

1950 Alan Turing proposes a test of machine intelligence

1952 W. S. McCulloch publishes the first scientific consideration of ethical machines

1968 In Stanley Kubrick's film *2001: A Space Odyssey*, the computer HAL 9000 famously turns against humans

1979 Robert Williams becomes the first person killed by a robot, in an assembly-line accident

1991 James Gips compares possible approaches to machine ethics in "Toward the Ethical Robot"

1993 Rodger Clarke critiques Asimov's laws

1997 World chess champion Garry Kasparov loses to IBM's Deep Blue supercomputer

2000 J. Storrs Hall introduces the expression "machine ethics"

2004 Michael Anderson and Susan Leigh Anderson's "Toward Machine Ethics" proposes programming ethical principles into robots

2010 Nao becomes the first robot whose behavior is guided by an ethical principle

1900 1950 2000

COURTESY OF RANDOM HOUSE (*Asimov book cover*); MGM/THE KOBAL COLLECTION (*HAL 9000*); AFP/GETTY IMAGES (*Kasparov and Deep Blue*)

time. It issues a reminder when the levels of duty satisfaction and violation have reached the point where, according to its ethical principle, reminding is preferable to not reminding. The robot notifies the overseer only when it gets to the point that the patient could be harmed, or could lose considerable benefit, from not taking the medication.

A full-fledged version of an ethical elder care robot—EthEl for short—would need a more complicated ethical principle to guide its broader range of behaviors, but the general approach would be the same. During its rounds in the assisted-living facility, the robot would use that principle to determine when one duty takes precedence over another. Here is how a typical day might unfold.

Early in the morning EthEl stands in a corner, plugged into the wall socket. Once her batteries fill up, her duty of beneficence ("do good") overrides her duty to maintain herself, so she starts making her way around the room, visiting residents and asking if she can be helpful in some way—get a drink, take a message to another resident, and so on. As she receives tasks to perform, she assigns initial levels of satisfaction and violation to each duty involved in the task. One resident, in distress, asks her to seek a nurse. Ignoring the distress of a resident means violating the duty of nonmaleficence ("prevent harm"). That duty now overrides her duty of beneficence, so she seeks a nurse to inform her that a resident is in need of her services. Once this task is completed, her duty of beneficence takes over again, and she resumes her rounds.

When the clock strikes 10 A.M., it is time to remind a resident to take his medication. This task, satisfying the duty of beneficence, becomes paramount, so she seeks the resident out and gives him his medication. Later, the residents are absorbed in a TV show—be it *The View* or *The Price Is Right*. With no other duties pending and with her batteries running low, EthEl finds her duty to herself to be increasingly violated, so she returns to her charging corner.

The study of machine ethics is only at its beginnings. Though preliminary, our results give us hope that ethical principles discovered by a machine can be used to guide the behavior of robots, making their behavior toward humans more acceptable. Instilling ethical principles into robots is significant because if people were to suspect that intelligent robots could behave unethically, they could come to reject autonomous robots altogether. The future of AI itself could be at stake.

Interestingly, machine ethics could end up influencing the study of ethics. The "real world" perspective of AI research could get closer to capturing what counts as ethical behavior in people than does the abstract theorizing of academic ethicists. And properly trained machines might even behave more ethically than many human beings would, because they would be capable of making impartial decisions, something humans are not always very good at. Perhaps interacting with an ethical robot might someday even inspire us to behave more ethically ourselves. SA

MORE TO EXPLORE

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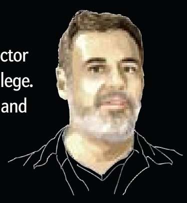

Frank W. Grasso is associate professor of psychology and director of the Biomimetic and Cognitive Robotics Lab at Brooklyn College. His research focuses on discovering mechanisms that control and coordinate behavior in octopuses and other marine animals and on building biologically inspired robots to test theories of those mechanisms.

BIOLOGY

Sensational Sucker

The octopus sucker can feel, taste, grip, manipulate—and act of its own accord

By Frank W. Grasso

AT FIRST GLANCE, AN OCTOPUS'S SUCKER LOOKS LIKE THE simple suction cup that tips a toy dart or affixes a GPS to the windshield. In fact, it is a remarkably sophisticated organ that not only can attach to objects with varying degrees of force but also can maneuver them, thanks to specialized muscle groups.

The sucker has two chambers: the outer infundibulum and inner acetabulum. When it attaches to an object—a tasty clam, for instance—the muscles of the infundibulum reshape the sucker rim to conform to the shell surface, forming a seal. The muscles of the acetabulum then contract, producing intense negative pressure inside the water-filled interior of the sucker relative to the external seawater. This pressure differential generates suction. The more the muscles of the acetabulum contract, the higher the negative pressure and the firmer the sucker's grip. So-called extrinsic muscles, meanwhile, permit the sucker rim to rotate the object in a full circle at a shallow or steep angle to the arm without breaking the seal or reducing the pressure differential.

In addition to their complex musculature, octopus suckers possess elaborate neural circuitry. Specialized neurons called chemoreceptors stud the sucker rim, enabling it to taste surfaces. Along with mechanoreceptors and proprioceptors—which relay information about touch and pressure and about muscle activity, respectively—these chemoreceptors feed into a bundle of neurons called a ganglion that appears to function as the sucker's own mini "brain," receiving sensory input and organizing coherent responses. Because the sucker ganglia are connected to one another through a chain of larger brachial ganglia running the length of the arm that control arm movements, neighboring suckers can coordinate their movements without relying on constant direction from the actual brain—to pass an object up or down the length of the arm, for example. Exactly how the brain and the arm and sucker ganglia divvy up neural responsibilities remains to be determined. SA

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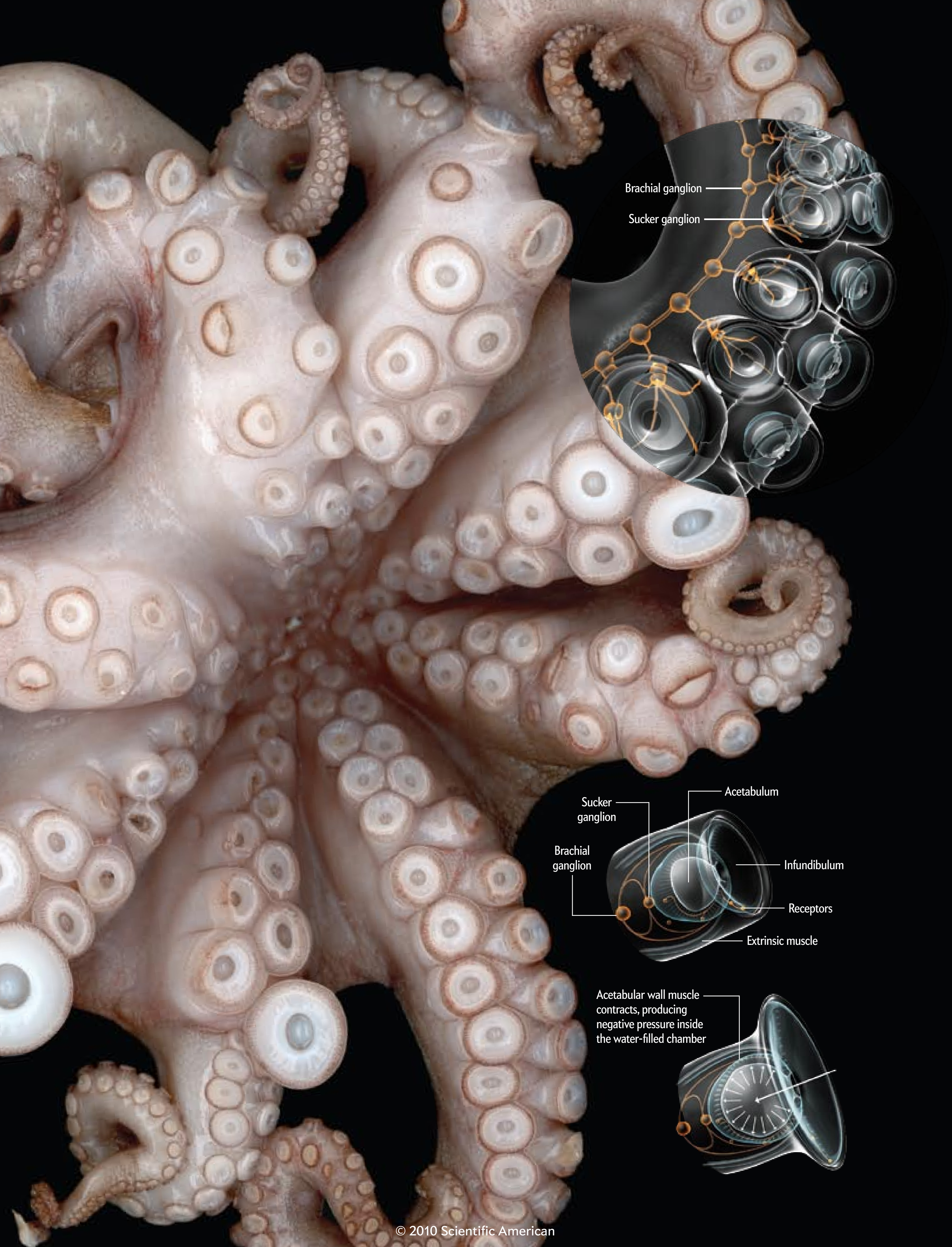
NEWMANN/CORBIS (*photograph*)

Illustrations by Bryan Christie


Brachial ganglion
Sucker ganglion
Sucker ganglion
Acetabulum
Brachial ganglion
Infundibulum
Receptors
Extrinsic muscle
Acetabular wall muscle contracts, producing negative pressure inside the water-filled chamber

MIND

Desperate for an Autism Cure

Diagnoses have soared, but valid treatments are few. Parents have turned instead to dubious, and often risky, alternative therapies

By Nancy Shute

Photography by Timothy Archibald

Nancy Shute has covered neuroscience and children's health issues for more than 20 years. She writes the On Parenting blog for *U.S. News & World Report,* where she is a contributing editor.

When Jim Laidler's oldest son, Benjamin, was diagnosed with autism, he and his wife started looking for help. "The neurologists were saying, 'We don't know what causes autism, and we don't know what the outcome for your son will be,'" Laidler relates. "No one was saying, 'Here's what causes it; here's what treats it.'"

But when the Laidlers, who live in Portland, Ore., searched the Web, they found dozens of "biomedical" treatments that promised to improve or even cure Benjamin's inability to talk, interact socially or control his movements. So the parents tried them on their son. They began with vitamin B_6 and magnesium, the nutritional supplements dimethylglycine and trimethylglycine, vitamin A, gluten- and casein-free diets, the digestive hormone secretin, and chelation, a drug therapy designed to purge the body of lead and mercury. They applied the purported treatments to Benjamin's little brother, David, who also was diagnosed with autism. Chelation did not seem to help much. Any effect from secretin was hard to tell. The diets showed promise; the Laidlers hauled special food with them everywhere. And Mom and Dad continued to feed the boys dozens of supplements, calibrating doses up and down with every change in behavior.

IN BRIEF

Fringe frenzy: As many at 75 percent of autistic children are receiving alternative treatments not developed by conventional medicine, which are often bogus.

Risky medication: Some practitioners prescribe drugs that are approved only for other conditions, have serious side effects and have never been tested for safety or efficacy in autism.

More science: In the past decade U.S. research funding for autism has increased by 15 percent a year, in part because of rising demand by parents for proved treatments and increased public awareness.

Genetic promise: Recently discovered genetic variations in children with autism could reveal a cause, but related therapies may be years away.

The first sign that their experiments had failed came when Laidler's wife, who had become increasingly skeptical, quit giving Benjamin supplements. She waited two months before telling her husband. Her silence ended the day Benjamin grabbed a waffle off a buffet during a family trip to Disneyland and wolfed it down. The parents watched with horror, convinced that he would regress the instant he went off his restricted diet. He didn't.

Jim Laidler should have known better. He is an anesthesiologist. He was aware from the beginning that the treatments he was using on his children had not been tested in randomized clinical trials, the gold standard for medical therapies. "At first I tried to resist," he says. But hope won out over skepticism.

Solid, scientific research simply does not exist for many autism treatments, and where it does, the number of children studied is often small.

Hundreds of thousands of parents every year succumb to the same desire to find something—anything—that might alleviate the symptoms of their struggling sons and daughters: lack of speech and communication, inept social interactions, repetitive or restrictive behaviors such as hand flapping or fixating on objects. As many as 75 percent of autistic children are receiving "alternative" treatments not developed by conventional medicine, according to some studies. And yet the therapies are often bogus. They have not been tested for safety or effectiveness, they can be expensive, and some of them may actually do harm. Fortunately, recent spikes in autism diagnoses and parent activism are pushing more federal and private funding toward research that could someday yield scientifically proved results.

NO CAUSE, NO CURE

THE DEMAND FOR AUTISM TREATMENTS is rising largely because more children are being diagnosed under broader criteria. Back in the 1970s, when autism was called "infantile psychosis"—a mix of social deficits and mental retardation—the condition was considered rare. Pediatricians would tell parents who were worried that, say, their eight-month-old wasn't making eye contact, to wait and see.

Studies indicated that about five children in 10,000 had autism, but the rate grew higher when doctors redefined the condition as autism spectrum disorder, which included milder symptoms. By the time an updated version of psychiatry's bible, the *Diagnostic and Statistical Manual of Mental Disorders,* known as the *DSM,* was published in 1994, doctors had added Asperger's syndrome—a high-functioning form popularized in the movie *Rain Man*—and a catchall group termed "pervasive developmental disorder, not otherwise specified." Doctors also started realizing the benefits of early diagnosis and treatment. In 2007 the American Academy of Pediatrics recommended universal screening of all children for autism between 18 and 24 months. By then, the autism rate had shot up to one in 110 children.

Whether greater diagnoses reflect a true rise in cases is a matter of controversy, because little is known about what causes the condition. "For the large majority of people with autism, we don't even know a clear-cut genetic factor," says David Amaral, research director of the MIND Institute at the University of California, Davis, and president of the International Society for Autism Research. No biomarkers are available to tell which children are at risk or to gauge how well treatments work. The greatest body of research is on behavioral interventions designed to teach social interaction and communication, which appear to help some children to varying degrees.

The lack of empirically vetted therapies makes it far easier for sellers of untested treatments to market hope. "What you've got is a combination of pseudoscience and fraud," says Stephen Barrett, a retired psychiatrist in Chapel Hill, N.C., who reports on dubious medical treatments at his Web site Quackwatch.com. "Parents are under a great deal of stress. They so want their kid to be better. They see improvement over time, and they give credit to the wrong thing." Those gains are not because of the "treatment," he says, but because children mature as they age.

Snake-oil salesmen litter the Web. One site tells parents they can "defeat the autism in your child" by buying a $299 book; another touts a video of "an autistic girl improving after receiving stem cell injections." Many parents acknowledge that they get their information from the Internet, and "a lot of parents rely on anecdotal reports, friends or other parents," says Brian Reichow, an associate research scientist at the Yale Child Study Center. "In autism, the research has not caught up with the treatments."

Hope doesn't come cheap, either. Alternative treatments such as lying in a pressurized, hyperbaric oxygen chamber (used to overcome compression sickness), which temporarily increases blood oxygen levels, cost $100 an hour or more, with one to two hourly sessions recommended daily. Sensory integration therapy, which can range from wrapping children in blankets or placing them in a hug machine to having them play with scented clay, can cost up to $200 an hour. Purveyors charge as much as $800 an hour for consultations and thousands more for vitamins, supplements and lab tests. Parents in an ongoing survey by the Interactive Autism Network at the Kennedy Krieger Institute in Baltimore report spending an average of $500 a month out-of-pocket. The one treatment for autism that has been proved to be somewhat effective—behavioral therapy—can also be the most expensive, at $33,000 or more a year. Although state early-intervention programs and public school districts often cover these costs, the wait for free evaluations and services can be long. All told, direct medical and nonmedical costs for autism add up to an average of $72,000 a year, according to the Harvard School of Public Health.

MEDICAL SNAKE OIL

UNPROVED THERAPIES extend to medications. Some practitioners prescribe drugs approved for other illnesses. The compounds include Lupron, which blocks the body's production of testosterone in men and estrogen in women; it is used to treat prostate cancer and to "chemically castrate" rapists. Doctors also have prescribed the diabetes drug Actos and intravenous immunoglobulin G, usually used for leukemia and pediatric AIDS. All three medications have serious side effects and have never been tested for safety or efficacy in autism.

Chelation, the primary treatment for lead poisoning, is another legitimate medical therapy turned autism "cure." The drug converts lead, mercury and other metals into chemically inert compounds that the body can excrete in urine. Some people think exposure to such metals, particularly the methylmercury used as a preservative in vaccines, can cause autism, even

Dubious Therapies

though no studies have demonstrated such a link. Indeed, autism diagnosis rates continued to climb after methylmercury was phased out of most vaccines in 2001. Chelation can cause kidney failure, particularly in the intravenous form favored for autism. In 2005 a five-year-old boy in Pennsylvania with autism died after being given intravenous chelation.

Concern led the National Institute of Mental Health to announce plans in 2006 for a randomized, controlled trial of chelation for autism. But the institute shelved the study in 2008 because officials could find "no clear evidence for direct benefit," and the treatment put the children at "more than a minimal risk." Their worry arose in part from lab studies that showed cognitive problems in rats that received chelation and did not have metal poisoning. "I don't think anybody had much faith that chelation would be the answer for a large number of children," says Thomas R. Insel, director of the NIMH. His researchers, he adds, are "more interested in testing medications that have a mechanistic basis."

Predictably, the abandoned study fueled charges that Big Science was ignoring alternative treatments. Money has always flowed more to discovering cures that work than to discrediting ones that don't. Until very recently, most autism research has been conducted in the social sciences and special education fields, where research budgets are modest and protocols are far different than medicine's. At times only a single child is involved in a study. "We would not even call it evidence," says Margaret Maglione, associate director of the Southern California Evidence-Based Practice Center at RAND, who is leading a federally funded review of behavioral treatments that will be published in 2011.

Graphic by Bryan Christie

MANY HAYSTACKS, FEW NEEDLES

STATE-OF-THE-ART SCIENTIFIC RESEARCH simply does not exist for many autism treatments, and where it does, the number of people studied is often small. In 2007 the Cochrane Collaboration, an independent evaluator of medical research, reviewed casein- and gluten-free diets, which are based on the premise that compounds in casein, a milk protein, and in gluten, a wheat protein, interfere with receptors in the brain. Cochrane identified two very small clinical trials, one with 20 participants and one with 15. The first study found some reduction in autism symptoms; the second found none. A new, randomized, controlled trial of 14 children, reported this past May by Susan Hyman, an associate professor of pediatrics at the University of Rochester School of Medicine and Dentistry, found no changes in attention, sleep, stool patterns or characteristic autistic behavior. "Slowly the evidence is starting to accumulate that [diet] is not the panacea people are hoping for," says Susan E. Levy, a pediatrician at Children's Hospital of Philadelphia who has evaluated the evidence with Hyman.

Levy has firsthand experience with the level of effort needed to sway public opinion. Secretin became a hot commodity after a 1998 study reported that three children had better eye contact, alertness and use of expressive language after being given the hormone during a diagnostic procedure for gastrointestinal problems. Media outlets, including *Good Morning America* and *Ladies' Home Journal,* recounted parents' joyous tales of children transformed. The National Institute of Child Health and Human Development rushed to fund clinical trials. By May 2005 five randomized clinical trials had failed to reveal any benefit, and interest in secretin waned. It took years for that to play out, says Levy, who helped conduct several of the trials: "Research is very labor-intensive, and progress may be slow." Parents may feel helpless, she adds, and "they don't want to leave any stone unturned."

The good news is that rising demand for proved treatments is attracting money for research. When the first International Meeting for Autism Research was held in 2001, barely 250 people attended. This past May 1,700 researchers, graduate students and parent advocates showed up for the meeting in Philadelphia. New technologies and increased public awareness have helped make autism a more appealing research focus. And in the mid-1990s parents began adopting the sophisticated lobbying and fund-raising tactics used for AIDS and breast cancer, leaning on foundations and the federal government.

Behavioral therapy—the one treatment that has been proved to be somewhat effective—can be the most expensive, at $33,000 or more a year.

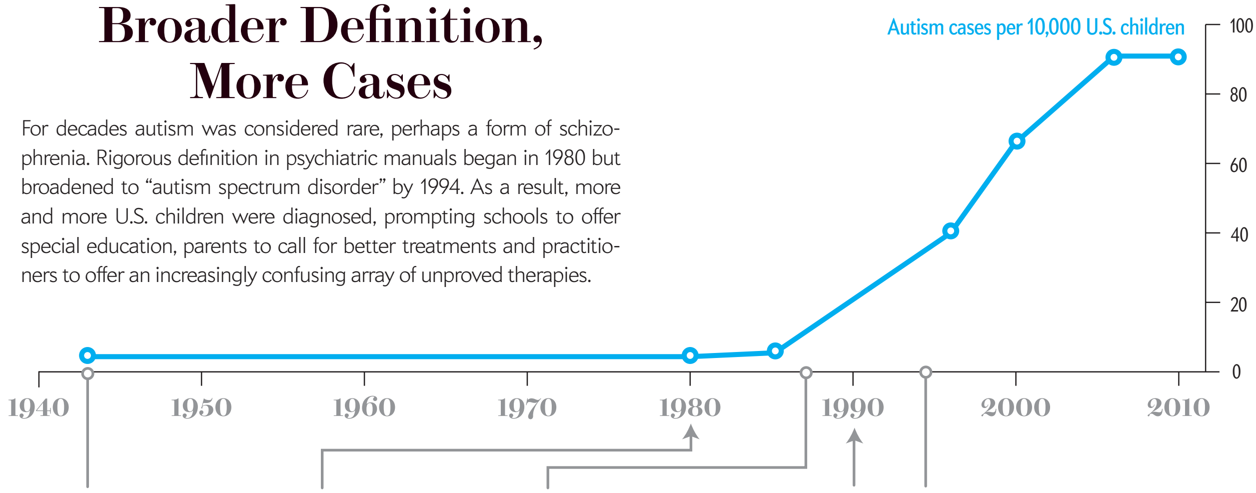
As a result, in the past decade U.S. research funding for autism has increased by 15 percent a year, with an emphasis on clinical applications. The National Institutes of Health allocated $132 million for autism work in 2009, with an additional $64 million from the American Recovery and Reinvestment Act, much of which is being earmarked to develop patient registries and other investigative tools. Private foundations, including the Simons Foundation and Autism Speaks, contributed $79 million in 2008. According to Autism Speaks, about 27 percent of all funding is being spent on investigating treatments, 29 percent on causes, 24 percent on basic biology and 9 percent on diagnosis.

These new pursuits encompass efforts to find out if early intervention with behavioral therapies that teach children social skills through repetition and reward can be used successfully with children when they are very young, when the brain is in the

DIAGNOSES

Broader Definition, More Cases

For decades autism was considered rare, perhaps a form of schizophrenia. Rigorous definition in psychiatric manuals began in 1980 but broadened to "autism spectrum disorder" by 1994. As a result, more and more U.S. children were diagnosed, prompting schools to offer special education, parents to call for better treatments and practitioners to offer an increasingly confusing array of unproved therapies.



1943 Autism defined.

1980 Autism first designated as its own category, infantile autism, in *DSM-III* (*Diagnostic and Statistical Manual of Mental Disorders,* third edition).

1987 Category changed to "autistic disorder" in revised *DSM-III;* eight of 16 criteria had to be met for a diagnosis.

1990 Autism first tracked under the Individuals with Disabilities Education Act, indicating need for special education.

1994 Autistic disorder, popularly known as autism spectrum disorder, is defined more broadly in *DSM-IV* to include syndromes such as Asperger's; only six diagnostic criteria had to be met.

SOURCES: U.S. CENTERS FOR DISEASE CONTROL AND PREVENTION, AMERICAN PSYCHIATRIC ASSOCIATION

Graphic by Bryan Christie

thick of learning language and social interaction. A study by several universities, released online in November 2009, found that children who were given two years of behavioral therapy for 31 hours a week, starting when they were between 18 and 30 months old, made substantial gains in IQ (17.6 points, compared with 7 points in the control group), and in skills of daily living and language. Seven of the 24 children in the treatment group improved enough that their diagnosis was upgraded from autism to the milder "not otherwise specified" form; only one child in the 24 who were given other interventions was given a milder diagnosis. The Autism Treatment Network has built a registry of more than 2,300 children for research on treatments for medical complications often suffered by autistic children, especially gastrointestinal issues and difficulty sleeping, and it plans to develop guidelines that could be used by pediatricians nationwide.

Jim Laidler calls current therapies "shamanism" but tried them on his sons anyway, out of desperation.

TOWARD A TRUE SCIENCE OF AUTISM

EFFORTS TO FIND MEDICATIONS, including those used in other neurological disorders, may have higher hurdles to clear. Medical interventions have been "a bit of a disappointment," Insel says. For example, antidepressants that boost the neurotransmitter serotonin in the brain are very effective in reducing the repetitive hand motions of obsessive-compulsive disorders, but a review by the Cochrane Collaboration reported in August that the drugs did nothing to alleviate the repetitive motions typical of autism. Among the new candidates are a medication that enhances REM sleep, which is lacking in children with autism, and oxytocin, a hormone that promotes childbirth and lactation and is thought to encourage mother-infant bonds. A study published in February by the National Center for Scientific Research in France found that 13 teenagers with Asperger's were better at identifying images of faces after inhaling oxytocin. A big leap would have to be made between that one study and the notion that oxytocin could mitigate autism's most devastating symptoms. Insel says: "We have a lot of work to do."

That work is starting to be done. In June a consortium of researchers who scanned the genes of 996 grade-schoolers found rare, novel genetic variations in children with autism. Some of the glitches affect genes that control communication across synapses—the contact points between neurons in the brain, a key focus of autism inquiries. "The actual mutations are different [among individuals], but there may be some commonalities in the biological pathways," says Daniel Geschwind, a professor of neurology and psychiatry at the David Geffen School of Medicine at U.C.L.A., a study leader. Geschwind is also a founder of the Autism Genetic Resource Exchange database of DNA samples from more than 1,200 families with autism, which was used in the study. Tests to confirm a culprit, or treatments that might fix the glitch, are still years away.

For now, more parents may be choosing not to experiment, if only so they can sleep at night. Michael and Alison Giangregorio of Merrick, N.Y., decided when their son, Nicholas, was diagnosed at age two that they would use only evidence-based treatments such as applied behavioral analysis. "It's difficult enough and challenging enough to help my son," Michael says. "I was not willing to try experimental therapies. I need to do what clinicians and researchers have taken the time to prove works and to prove that it doesn't do any additional harm." Nicholas is now nine, and although he remains nonverbal, behavioral therapy has taught him to use physical signals when he needs to go to the bathroom. He can now wash his hands, sit through dinner in a restaurant and walk down an aisle in the drugstore without flapping his hands. "Obviously, the goal of my family, and most families, is to lead as normal a life as possible," says Michael, a 45-year-old Wall Street trader. "Normal is going out to dinner as a family."

Jim Laidler's path to the same place was far more crooked. Although he embraced alternative treatments for his sons, he also tried to persuade practitioners that they needed to apply the rigor of mainstream science in evaluating such options. "I kept harping on it. Did you do any controls?" he says. His oldest son, now 17, will probably never be able to live on his own, yet his younger son is in a regular middle school. Of the many treatments the family tried, Laidler, 51, says: "This is basically shamanism in a lab coat." Thousands of desperate parents are hoping that science will one day offer stronger medicine. SA

MORE TO EXPLORE

Autism Genetic Resource Exchange, an open-access registry of DNA from families with autism: www.agre.org

Autism Speaks advocacy group, funded research: www.autismspeaks.org/science/science_news/index.php

U.S. Centers for Disease Control and Prevention overview of research and parent information: www.cdc.gov/ncbddd/autism/index.html

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/oct2010

Antonio Regalado is a science and technology reporter and the Latin America contributor to *Science* magazine. He lives in São Paulo, Brazil, where he writes about energy topics, including renewables.

ENERGY

Reinventing the Leaf

The ultimate fuel may come not from corn or algae but directly from the sun itself

By Antonio Regalado

LIKE A FIRE-AND-BRIMSTONE PREACHER, NATHAN S. Lewis has been giving a lecture on the energy crisis that is both terrifying and exhilarating. To avoid potentially debilitating global warming, the chemist from the California Institute of Technology says civilization must be able to generate more than 10 trillion watts of clean, carbon-free energy by 2050. That level is three times the U.S.'s average energy demand of 3.2 trillion watts. Damming up every lake, stream and river on the planet, Lewis notes, would provide only five trillion watts of hydroelectricity. Nuclear power could manage the feat, but the world would have to build a new reactor every two days for the next 50 years.

Before Lewis's crowds get too depressed, he tells them there is one source of salvation: the sun pours more energy onto the earth every hour than humankind uses in a year. But to be saved, Lewis says, humankind needs a radical breakthrough in solar-fuel technology: artificial leaves that will capture solar rays and churn out chemical fuel on the spot, much as plants do. We can burn the fuel, as we do oil or natural gas, to power cars, create heat or generate electricity, and we can store the fuel for use when the sun is down.

Lewis's lab is one of several that are crafting prototype leaves, not much larger than computer chips, designed to produce hydrogen fuel from water, rather than the glucose fuel that natural leaves create. Unlike fossil fuels, hydrogen burns clean. Other researchers are working on competing ideas for capturing the sun's energy, such as algae that has been genetically altered to pump out biofuels, or on new biological organisms engineered to excrete oil. All these approaches are intended to turn sunlight into chemical energy that can be stored, shipped and easily consumed. Lewis argues, however, that the man-made leaf option is the most likely to scale up to the industrial levels needed to power civilization.

FUEL FROM PHOTONS

ALTHOUGH A FEW LAB PROTOTYPES have produced small amounts of direct solar fuel—or electrofuel, as the chemicals are sometimes called—the technology has to be improved so the fuel can be

IN BRIEF

Natural energy: Plants produce their own chemical fuel—sugar—from sunlight, air and water, without producing harmful emissions.

Man-made leaf: Researchers are devising artificial leaves that could similarly convert sunlight and water into hydrogen fuel, which could be burned to power cars, create heat or generate electricity, ending dependence on fossil fuels.

Nano solution: To be practical, this solar-fuel technology would have to be made cheaply in thin, flexible sheets, perhaps from silicon nanowires, and use inexpensive catalysts that help to generate hydrogen efficiently.

Artificial leaves could use sunlight to produce hydrogen fuel for cars and power plants.

Illustrations by Cherie Sinnen

manufactured on a massive scale, very inexpensively. To power the U.S., Lewis estimates the country would need to manufacture thin, flexible solar-fuel films, instead of discrete chiplike devices, that roll off high-speed production lines the way newsprint does. The films would have to be as cheap as wall-to-wall carpeting and eventually cover an area the size of South Carolina.

Far from being a wild dream, direct solar-fuel technology has been advancing in fits and starts ever since President Jimmy Carter's push for alternative energy sources during the 1970s oil shocks. Now, with a new energy and climate crunch looming, solar fuel is suddenly gaining attention. Researcher Stenbjörn Styring of Uppsala University in Sweden, who is developing artificial systems that mimic photosynthesis, says the number of consortiums working on the challenge has ballooned from just two in 2001 to 29 today. "There are so many we may not be counting correctly," he adds.

In July the Department of Energy awarded $122 million over five years to a team of scientists at several labs, led by Lewis, to develop solar-fuel technology, one of the agency's three new energy research priorities. Solar fuels "would solve the two big problems, energy security and carbon emissions," says Steven E. Koonin, the top science administrator at the DOE. Koonin thinks sun-to-fuel schemes face "formidable" practical hurdles but says the technology is worth investing in because "the prize is great enough."

If we want to save the planet, we have to get rid of all those noble metals and work with cheap minerals like iron to catalyze reactions.

In photosynthesis, green leaves use the energy in sunlight to rearrange the chemical bonds of water and carbon dioxide, producing and storing fuel in the form of sugars. "We want to make something as close to a leaf as possible," Lewis says, meaning devices that work as simply, albeit producing a different chemical output. The artificial leaf Lewis is designing requires two principal elements: a collector that converts solar energy (photons) into electrical energy (electrons) and an electrolyzer that uses the electron energy to split water into oxygen and hydrogen. A catalyst—a chemical or metal—is added to help achieve the splitting. Existing photovoltaic cells already create electricity from sunlight, and electrolyzers are used in various commercial processes, so the trick is marrying the two into cheap, efficient solar films.

Bulky prototypes have been developed just to demonstrate how the marriage would work. Engineers at Japanese automaker Honda, for example, have built a box that stands taller than a refrigerator and is covered with photovoltaic cells. An electrolyzer, inside, uses the solar electricity to break water molecules. The box releases the resulting oxygen to the ambient air and compresses and stores the remaining hydrogen, which Honda would like to use to recharge fuel-cell cars.

In principle, the scheme could solve global warming: only sunlight and water are needed to create energy, the by-product is oxygen, and the exhaust from burning the hydrogen later in a fuel cell is water. The problem is that commercial solar cells contain expensive silicon crystals. And electrolyzers are packed with the noble metal platinum, to date the best material for catalyzing the water-splitting reaction, but it costs $1,500 an ounce.

That means Honda's solar-hydrogen station will never power the world. Lewis calculates that to meet global energy demand, future solar-fuel devices would have to cost less than $1 per square foot of sun-collecting surface and be able to convert 10 percent of that light energy into chemical fuel. Fundamentally new, massively scalable technology such as films or carpets made from inexpensive materials are needed. As Lewis's Caltech colleague Harry A. Atwater, Jr., puts it, "We need to think potato chips, not silicon chips."

FINDING A CATALYST

THE SEARCH FOR SUCH TECHNOLOGY remains at an early stage, despite several decades of on-again, off-again work. One pioneering experiment shows why. In 1998 John Turner of the National Renewable Energy Laboratory in Golden, Colo., built a device about the size of a matchbook that when placed in water and exposed to sunlight kicked out hydrogen and oxygen at a prodigious rate and was 12 times as efficient as a leaf. But Turner's creation depended on rare and expensive materials, including platinum as the catalyst. By one estimate, Turner's solar-fuel cell cost $10,000 per square centimeter. That might do for military or satellite applications, but not to power civilization.

Noble metals, often the best catalysts, are in short supply. "That's the big catch in this game," Styring says. "If we want to save the planet, we have to get rid of all those noble metals and work with cheap minerals like iron, cobalt or manganese." Another difficulty is that the water-splitting reaction is highly corrosive. Plants handle that by constantly rebuilding their photosynthetic machinery. Turner's solar-fuel cell lasted just 20 hours.

Today Turner's research is consumed with devising successive generations of catalysts that each are a bit cheaper and of solar collectors that each last a little longer. At times the search is agonizingly hit or miss. "I am wandering through the forest looking for a material that does what I want," Turner says. "Progress has been minimal."

Other teams are also chasing catalysts, including one led by Daniel G. Nocera of the Massachusetts Institute of Technology. In 2008 Nocera and a colleague hit on an inexpensive combination of phosphate and cobalt that can catalyze the production of oxygen—one necessary part of the water-splitting reaction.

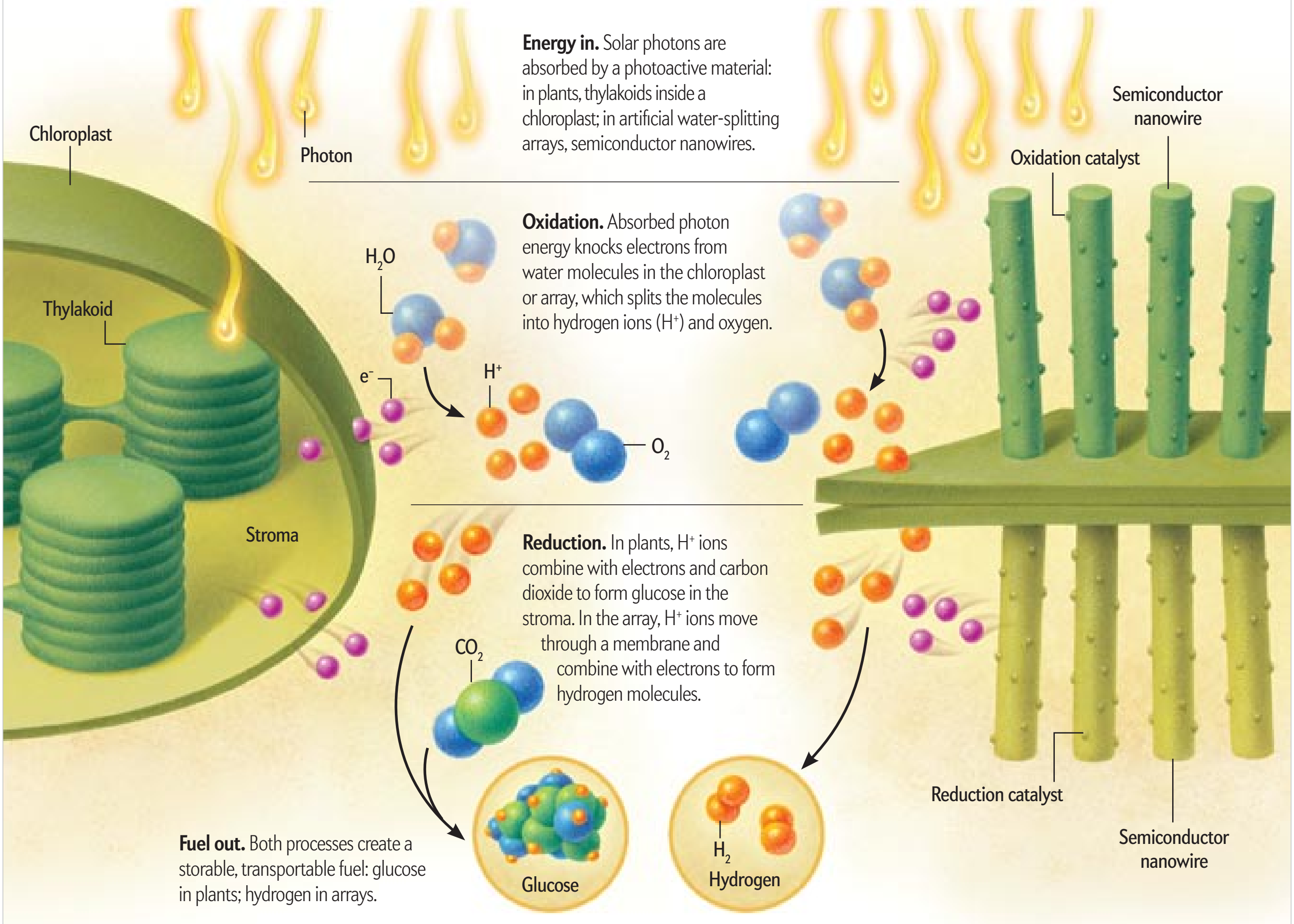
Even though the prototype device was just a piece of the puzzle—the researchers did not find a better catalyst for creating hydrogen, the actual fuel—M.I.T. touted it as a "major leap" toward "artificial photosynthesis." Nocera began predicting that Americans would soon be cooking up hydrogen for their cars using affordable backyard equipment. Those bold claims have not sat well with some solar-fuel experts, who maintain that research has decades to go. Others are more bullish: the DOE and the venture capital firm Polaris Venture Partners are supporting Nocera's ongoing work at Sun Catalytix, a company he created in Cambridge, Mass.

At Caltech, meanwhile, Lewis has been working on a way to collect and convert the sun's photons—the first step in any solar-fuel device—that is much cheaper than conventional, crystalline silicon solar cells. He has designed and fabricated a collector made of silicon nanowires embedded in a transparent plastic film that, when made larger, could be "rolled and unrolled like a blanket," he says [*see box on opposite page*]. His nanowires can convert light into electric energy with 7 percent efficiency. That

Solar Nanowires Mimic Nature

Plants harness the sun's energy to convert carbon dioxide and water into glucose—chemical fuel that can be used or stored (*left*). Researchers are devising artificial leaves that use sunlight to split water molecules, creating hydrogen fuel. Nathan Lewis's group at the California Institute of Technology is designing a small leaf with arrays of silicon nanowires that could produce hydrogen (*right*).

Natural Leaf | **Artificial Leaf**



pales in comparison to commercial solar cells, which are up to 20 percent efficient. But if the material could be made inexpensively enough—those sheets rolling off a press like newsprint—lower efficiency could be acceptable.

Researchers also debate whether hydrogen is the best choice for solar fuel. Teams working with biological organisms that produce liquid biofuels say these fuels are easier to store and transport than hydrogen. But hydrogen gas is flexible, too: it can be used in fuel-cell cars, burned in power plants to generate electricity, and even serve as a feedstock in producing synthetic diesel. Nevertheless, "the key is to make an energy-dense chemical fuel," with minimal carbon emissions, Lewis says. "Let's not get hung up on which one."

Real-life leaves prove that sunlight can be converted into fuel using only common elements. Can humankind imitate this process to rescue the planet from global warming? The prognosis is not clear. "The fact that we can't solve the problem with off-the-shelf components is why it's an exciting time to be working in this area," Lewis says. But he is worried that society—including policy makers, government funding agencies and even scientists—still has not grasped the size of the energy problem or why revolutionary solutions are needed. That is why he spends so much time on the lecture circuit, preaching solar salvation: "We are not yet treating this problem like one where we can't afford to fail." SA

MORE TO EXPLORE

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INFORMATION SCIENCE

Digitizer in Chief

The first step toward transparent government, says White House information czar Vivek Kundra, is to make all its information freely available on the Web

Interview by Michael Moyer

THE FEDERAL GOVERNMENT IS MANY things, but transparent it is not. As the nation's first chief information officer, Vivek Kundra is attempting to pull the federal infrastructure into the information age by making government data freely available online. Is it possible for technology to revolutionize the way we interact with government?

SCIENTIFIC AMERICAN: We all know that the White House has a Facebook page. Beyond that, what ways can the government use technology to better serve taxpayers?

KUNDRA: The power of information technology is in far more than just setting up a Web site or serving up content on Facebook or Twitter. I look at Government 2.0 as a fundamental reengineering of how the American people interact with their government.

Just consider the huge experience gap that Americans have when they go online to make a hotel reservation or buy a book through Amazon versus how they interact with the public sector. In the public sector—whether it's paying taxes, applying for student aid or applying for Social Security benefits—that experience involves turning in paper forms, waiting in line or waiting on hold on the phone.

Part of what we're trying to do is fundamentally reengineer the back-end systems, the processes, to make sure that the experience the American people have with the government looks much more like the experience they have when they interact with a private-sector company.

If we accept that much of the trouble with government can be framed as a customer service issue, how can technology help fix this?

IN BRIEF

The federal government has begun a program to place all nonclassified information online in formats that make it simple for researchers and developers to work with.

By opening up this information to the public, federal chief information officer Vivek Kundra hopes to reduce government waste and make it easier for citizens to interact with government.

Kundra has also introduced the Information Technology Dashboard, a Web-based service that allows citizens to track the progress of various federal IT infrastructure projects.

Privacy and security remain major challenges. Government databases often contain information about individual citizens, and that information must be stripped out before posting.

STEPHEN VOSS *Redux Pictures*

Big data: Vivek Kundra, 36, wants to consolidate the government data scattered over 24,000 separate Web sites into a single portal.

Unfortunately, a lot of people dismiss online reservations or book purchases as a kind of lightweight customer service application. What they don't realize is the complexity that's abstracted on these back-end systems. The government has not kept pace with this innovation. There just isn't the Darwinian pressure that you see in the private sector. Part of what we're focused on is making sure that we close the technology gap.

Tech czar Kundra in the District of Columbia's technology "war room."

JAMES M. THRESHER *Washington Post/Getty Images*

And you can do this by placing government databases online?
It's part of the larger trend of what's happening online. Look at YouTube and look at Apple. Now, YouTube didn't go out there and create all these videos. YouTube essentially built the platform, and a third party created all that content. Same thing with Apple—Apple didn't go out there and create the most innovative applications you find on the iPhone. A third party created those applications.

In the same way, what we're trying to do is figure out how to move toward government as a platform. In this way, we can tap into the ingenuity of the American people and empower the American people to solve some of the most difficult problems and challenges we face as a country. There's a recognition that the federal government does not have a monopoly on the best ideas and that the best ideas don't necessarily live within the four walls of Washington.

How much progress have you made?
When Data.gov was launched, we launched it with 47 data sets about a year ago. Today it has more than 272,000 data sets.

But more important, we've been encouraging communities of innovators, developers and watchdogs to actually use those data in three ways: one, to hold government accountable; two, to create innovative applications; and three, to find breakthroughs at the intersection of multiple data sets.

What do you mean by that, "breakthroughs at the intersection of multiple data sets?"
Well, just like in life, true value lies at the intersection of multiple disciplines. If we look at music and mathematics, that's where true value lies. It's the same for data.

Just to give you a very basic example, when [in 2000] the Department of Defense made the decision to stop scrambling the data from the Global Positioning System, it essentially gave birth to the GPS industry. At the time people could not have imagined that all of a sudden we would have the ability to go to our local car rental store and for about 10 bucks rent a GPS device in a new city we were navigating.

But more interestingly, we can now combine that real-time GPS data with crime data or health care data. All of a sudden, what we end up with as citizens is better services, better insight into how society functions, and a government that is able to more intelligently serve the American people.

Yet "open" is not the default setting in government. To take just one example, in 2001 then attorney general John Ashcroft sent a memo to the heads of federal agencies encouraging them to block as many Freedom of Information Act requests as possible. How do you reverse this reflex and institutionalize the open-government effort?
On his first full day in office, President Obama issued a memorandum on transparency and open government. And part of that memorandum challenged us to hardwire the philosophical principles around transparency, participation and open government into everything we do. We're changing the default setting of the public sector from one that is closed, secretive and opaque to one that is open, transparent and participatory. And every agency was charged with releasing high-value, information-rich data sets as part of the open-government directive.

What practical benefits have come from opening up those data?
Well, let me give you two very specific examples of what happens when you shine light on the operations of government. The first is cost savings. In the private sector, one third of information technology projects ends up getting terminated if they don't perform. In the public sector, we never kill anything.

Now we have launched the Information Technology Dashboard, which publishes data about every major IT investment in the U.S. government. As soon as we went live, the Department of Veterans Affairs essentially halted 45 IT projects, terminating 12. Those 12 terminated projects saved about $54 million. Then a couple of weeks ago at the Office of Management and Budget, we halted over 30 major financial systems that were not performing well. That's about $3 billion in annual spending on the systems that were way behind schedule and way over budget. And just last week we terminated a Veterans Department financial system that was about $400 million over budget and years behind schedule. Instead of putting good money after bad money, we decided to terminate that project. That's one example, accountability as a result of shining a light on the operations of government.

The second example is applications. We released aviation data from the Department of Transportation, and all of a sudden we saw a competition set up by the Sunlight Foundation [a nonprofit organization that advocates transparency in government]

to develop applications. And as a function of that, some developers created an app called FlyOnTime.us that allows you to see average landing times and takeoff times for every flight in the country as well as real-time data on wait times at airports.

Professor James A. Hendler of the Rensselaer Polytechnic Institute has set up a team of about eight students who are developing some of the most creative applications that use the Semantic Web to slice and dice information across the public sector. They have made it possible to see who was visiting the White House and when, where we're distributing foreign aid funding, and how we're performing in terms of environment and health care.

These are some really, really innovative applications. And these applications are being created in ways that would have cost us millions of dollars, and we would have ended up with a poor product. There are more than 24,000 Web sites in the U.S. government. Yet when you look at some of the most innovative applications, you can see how we can slice and dice the available data to provide a much better customer-facing experience than we have so far.

In the U.S. today, we have a number of enormous challenges—energy security, global warming, health care and long-term deficit problems, for starters. Is opening up the federal IT going to be able to have a real impact on the big things, or are we just nibbling around the edges here?

Well, I think it's going to have a huge impact on major policy issues, too. If we go back in history, one of the things we have to recognize is technology is fundamentally changing the equation. It used to be that, in the olden days, people would gather around a public square, the Agora, to petition their government, to conduct commerce, and it was a physical public square. Today we can actually create a digital public square and have a front-row seat to how our government works in ways we never could have done before. With this vast array of data on every aspect of government operations—whether it's health care, whether it's the environment, whether it's education—we can shift our debate to have us much more focused on facts and science than conjecture. And it also provides for the first time the ability for the American people to lift the veil on how their government actually functions.

Think about the health care system. If you go online today, you have the ability to compare consumer products to one another. You can compare cars in terms of gas mileage and 0 to 60 speed, or you can compare cameras based on aperture and price. Yet when we think about health care, it's been very difficult, historically, to compare one hospital to another, one doctor to another.

There used to be a Web site called Hospital Compare that the Department of Health and Human Services ran for years. Yet it wasn't very well utilized. The American people didn't really have access to it. But by democratizing those data something really interesting happened.

The Bing search engine took this Hospital Compare data, and now if you're in front of a computer and you type the name of a hospital on Bing.com, what you'll see is the average rating by patients of that hospital and typical outcomes in that hospital. It's information that's at your fingertips that before you would have had to navigate a vast bureaucracy to get access to those data.

Today we can create a digital public square and have a front-row seat to how our government works in ways we never could have done before.

You mentioned earlier that it's very difficult for the average citizen to interact with an agency like the IRS. Why can't we just go online, and fill out a form, and take 20 minutes to do our taxes every year? Why do we have to pay accountants billions of dollars to do it for us?

That's part of what the IRS is actually undergoing right now—a modernization of its back-end systems to really focus on the customer. Historically, what we've seen in the federal government, unfortunately, is that people have focused very much internally on how the bureaucracy operates, rather than how their customers operate.

And part of what we're trying to achieve here is to make sure that there's enough pressure to basically close the gap between the consumer experience in our private life and our experience with the public sector.

A very specific example is what we've been able to do in a partnership between the Department of Education and the IRS. It used to be that you would have to fill out a very exhaustive questionnaire when you're filling out an application for student aid. And the agencies would not share data.

But what we've been able to do is bring the IRS and the Department of Education to the table together to partner, to streamline the application process for student aid. Now as a result of that effort, we've been able to eliminate dozens of questions on the student aid form and fundamentally reengineer that experience so that those forms are prepopulated with data that the government already has.

On the other hand, I'm not sure I want the IRS to be sharing how much money I make with other government agencies. How do we build in systems to protect our privacy?

That's part of the challenge. Even when we're talking about Data.gov and democratizing data, one of the things we have to be very mindful of is the mosaic of facts. Individual data sets may not reveal anything, but when they're combined, it opens up the ability to get access to information that may be sensitive in nature. That's why before data sets are put on Data.gov, agencies are scrubbing those data sets to make sure that they can't be sliced and diced in a way that would compromise privacy or national security in any way.

But in terms of government sharing information, you're absolutely right, and that's why it's just a very deliberative effort to make sure that, first and foremost, we're protecting the privacy of the American people and that as information is shared, it's done so on an as-needed basis. SA

MORE TO EXPLORE

The Semantic Web. Tim Berners-Lee, James Hendler and Ora Lassila in *Scientific American,* Vol. 284, No. 5; pages 28–37; May 2001.
Data.gov Wiki is at **http://data-gov.tw.rpi.edu/wiki**
Information on the Semantic Web and Data.gov is at **www.data.gov/semantic**
Information Technology Dashboard is at **http://it.usaspending.gov/**
Web Science, a blog by James Hendler, is at **http://blogs.nature.com/jhendler**

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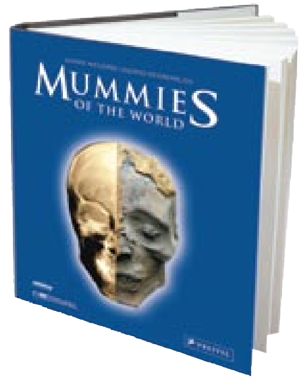
Mummies from South America



Mummies of the World

edited by Alfried Wieczorek and Wilfried Rosendahl. Prestel, 2010 ($65)

People have been preserving bodies of the dead for millennia, from the bog bodies found in the peat wetlands of northern Europe to the embalmed and wrapped mummies recovered from Egypt's desert sands. The companion book to a traveling exhibit of the same name that opened in California in July, this volume brings together evocative imagery of dozens of mummies—human and animal—from around the globe and explains how science is revealing who these individuals were and how their remains have survived across the ages.

EXCERPT

What Technology Wants

by Kevin Kelly. Viking, 2010 ($27.95)

Technology, *contends journalist Kevin Kelly, has a life of its own, and it advances independently of humans. Here he describes what he calls the "technium," a term that embodies the sum of all technologies, the society and culture of tools, and the self-reinforcing system of creating them.*

"At some point in its evolution, our system of tools and machines and ideas became so dense in feedback loops and complex interactions that it … began to exercise some autonomy.

"At first the notion of technological independence is very hard to grasp. We are taught to think of technology first as a pile of hardware and secondly as inert stuff that is wholly dependent on us humans. In this view, technology is only what we make. Without us, it ceases to be. It does only what we want. And that's what I believed, too.... But the more I looked at the whole system of technological invention, the more powerful and self-generating I realized it was.

"There are many fans, as well as many foes, of technology who strongly disagree with the idea that the technium is in any way autonomous. They adhere to the creed that technology does only what we permit it to do. In this view, notions of technological autonomy are simply wishful thinking on our part. But I now embrace a contrary view: that after 10,000 years of slow evolution and 200 years of incredible intricate exfoliation, the technium is maturing into its own thing. Its sustaining network of self-reinforcing processes and parts has given it a noticeable measure of autonomy. It may have once been as simple as an old computer program, merely parroting what we told it, but now it is more like a very complex organism that often follows its own urges."

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ALSO NOTABLE

BOOKS

The Moral Landscape: How Science Can Determine Human Values, by Sam Harris. Free Press, 2010 ($26.99)

Eels: An Exploration, from New Zealand to the Sargasso, of the World's Most Mysterious Fish, by James Prosek. HarperCollins, 2010 ($25.99)

Genetic Twists of Fate, by Stanley Fields and Mark Johnston. MIT Press, 2010 ($24.95)

Judging Edward Teller: A Closer Look at One of the Most Influential Scientists of the Twentieth Century, by Istvan Hargittai. Prometheus Books, 2010 ($32)

Virtual Words: Language on the Edge of Science and Technology, by Jonathon Keats. Oxford University Press, 2010 ($19.95)

The Vertical Farm: Feeding Ourselves and the World in the 21st Century, by Dickson Despommier. Thomas Dunne Books, 2010 ($25.99)

Delusions of Gender: How Our Minds, Society, and Neurosexism Create Difference, by Cordelia Fine. W. W. Norton, 2010 ($25.95)

FOR KIDS

Bones: Skeletons and How They Work, by Steve Jenkins. Scholastic, 2010 ($16.99)

Biggest Bugs Life-Size, by George Beccaloni. Firefly Books, 2010 ($19.95)

BLOGS

Rennie's Last Nerve, by former *Scientific American* editor in chief John Rennie. **http://johnrennie.net**

History of Science Center's blog, by the librarians, archivists and curators of the Center of History of Science at the Royal Society in the U.K. **http://blogs.royalsociety.org/history-of-science**

COURTESY OF PRESTEL AND THE REISS-ENGELHORN-MUSEUM MANNHEIM, GERMANY

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). He is author of *Why Darwin Matters* and blogs at BigQuestionsOnline.com.

Can You Hear Me Now?

Physics shows that cell phones cannot cause cancer

Baseball legend Yogi Berra is said to have fretted, "I don't want to make the wrong mistake." As opposed to the right mistake? A mistake that is both wrong and right is the alleged connection between cell phone use and brain cancers. Reports of a link between the two have periodically surfaced ever since cell phones became common appendages to people's heads in the 1990s. As recently as this past May 17, *Time* magazine reported that despite numerous studies finding no connection between cell phones and cancer, "a growing band of scientists are skeptical, suggesting that the evidence that does exist is enough to raise a warning for consumers—before mass harm is done."

Their suggestion follows the precautionary principle, which holds that if something has any potential for great harm to a large number of people, then even in the absence of evidence of harm, the burden of proof is on the unworried to demonstrate that the danger is not real. The precautionary principle is a weak argument for two reasons: (1) it is difficult to prove a negative—that there is no effect; (2) it raises unnecessary public alarm and personal anxiety. Cell phones and cancer is a case study in the precautionary principle misapplied, because not only is there no epidemiological evidence of a causal connection, but physics shows that it is virtually impossible for cell phones to cause cancer.

The latest negative findings mentioned by *Time* come out of a $24-million research project published in the *International Journal of Epidemiology* ("Brain Tumour Risk in Relation to Mobile Telephone Use"). It encompassed more than 12,000 long-term regular cell phone users from 13 countries, about half of whom were brain cancer patients, which let researchers compare the two groups. The authors concluded: "Overall, no increase in risk of glioma or meningioma [the two most common types of brain tumors] was observed with use of mobile phones. There were suggestions of an increased risk of glioma at the highest exposure levels, but biases and error prevent a causal interpretation. The possible effects of long-term heavy use of mobile phones require further investigation."

This application of the precautionary principle is the wrong mistake to make. Cell phones cannot cause cancer, because they do not emit enough energy to break the molecular bonds inside cells. Some forms of electromagnetic radiation, such as x-rays, gamma rays and ultraviolet (UV) radiation, are energetic enough to break the bonds in key molecules such as DNA and thereby generate mutations that lead to cancer. Electromagnetic radiation in the form of infrared light, microwaves, television and radio signals, and AC power is too weak to break those bonds, so we don't worry about radios, televisions, microwave ovens and power outlets causing cancer.

Where do cell phones fall on this spectrum? According to physicist Bernard Leikind in a technical article in *Skeptic* magazine (Vol. 15, No. 4), known carcinogens such as x-rays, gamma rays and UV rays have energies greater than 480 kilojoules per mole (kJ/mole), which is enough to break chemical bonds. Green-light photons hold 240 kJ/mole of energy, which is enough to bend (but not break) the rhodopsin molecules in our retinas that trigger our photosensitive rod cells to fire. A cell phone generates radiation of less than 0.001 kJ/mole. That is 480,000 times weaker than UV rays and 240,000 times weaker than green light!

Even making the cell phone radiation more intense just means that there are more photons of that energy, not stronger photons. Cell phone photons cannot add up to become UV photons or have their effect any more than microwave or radio-wave photons can. In fact, if the bonds holding the key molecules of life together could be broken at the energy levels of cell phones, there would be no life at all because the various natural sources of energy from the environment would prevent such bonds from ever forming in the first place.

Thus, although in principle it is difficult to prove a negative, in this case, one can say it is impossible for cell phones to hurt the brain—with the exception, of course, of hitting someone on the head with one. QED. SA

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/oct2010

Illustration by Marcos Chin

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column for 100 years, within an order of magnitude. He also hosts the *Scientific American* podcast Science Talk.

Real Skyscrapers

Cities' coarse coasts cause cyclonic course corrections

One of my favorite things about New York City is our almost complete lack of earthquakes and hurricanes. Most reviews of the city don't start with its lack of natural disasters, but I also love spaghetti because it doesn't have any bones. Of course, New Yorkers do suffer the occasional small temblor, but those are indistinguishable from the shaking caused by subways, truck traffic or incredibly powerful bass notes coming from car stereos blocks away. And we haven't had a decent hurricane in my lifetime, although the October 1991 weather event that became known as the Perfect Storm was impressive: because of the driving rain, every stick in the Tri-State area, whether on the ground or flying through the air, served as an infallible divining rod.

Records show that a good-size hurricane hits the New York area every 75 years or so, meaning I may get lucky and see one, or I may get luckier and not see one. But maybe the odds of seeing one are slightly better than I thought. Because, as I just learned, computer models suggest that the very city I love for its lack of hurricanes—along with any other city on a coast—may actually attract monster storms.

Cities, it turns out, are rough. Sure, they're also tumble, but the roughness in this case is a measure of their topography. Farmland is nice and smooth. Forests have some roughness, with all those trees sticking up and out. But a big city will leave a nasty rug burn on, say, any giant prehistoric lizard, awakened from hibernation by a nuclear explosion, that slides across it.

Here's how that urban roughness gives hurricanes the come-hither. When a hurricane starts to sample the land, the friction of jagged cities slows down the leading edge more than any adjacent smoother surface does (with all other factors, such as available moisture, being equal). The back of the hurricane hasn't gotten the news yet, so there's a pileup.

The squeezed air goes up, condensing its water vapor and giving off heat. Which feeds energy back into the nearby part of the hurricane, making it move faster and pulling the rest of the storm in that direction.

Or, as Johnny Chan and Andie Au-Yeung of the City University of Hong Kong put it in a paper that will appear in the *Journal of Geophysical Research (Atmospheres):* "Higher roughness induces stronger convergence and hence increases the vertical advection term in the potential vorticity tendency distribution over the rougher area. Hence, a TC (tropical cyclone) tends to move towards a region with higher roughness"—that is, toward my house. Sure, it's not just toward *my* house. But as Yossarian, the hero of Joseph Heller's novel *Catch-22,* notes when he complains that the enemy is trying to kill him, and his fellow fliers respond that the enemy is trying to kill all of them, "What difference does that make?"

Something else that settles into cities more than into the surrounding countryside is heat. The well-known "urban heat-island effect" is ticking off more people, because (a) more people than ever live in cities, neighbor cheek by jowl with annoyed neighbor, and (b) it sure has been hot. It's been so hot that french fries in Germany are expected to be half an inch shorter than usual because the potatoes aren't growing as large. Conversely, Italian ices everywhere have been going through the roof.

Speaking of roofs, they could be put to work to cool down cities, according to a recent article in *Physics World*. The review cites work by the Urban Heat Island Research Group at Lawrence Berkeley National Laboratory, which modeled what Los Angeles would be like if the albedo (the ratio of light reflected versus that received) of its buildings and road surfaces were 30 percent higher. Bouncing the light away better translates into the town being a full two degrees Celsius cooler. Two degrees in New York City could be the difference between staying inside with the air conditioner running and going outside. Where we could dissuade hurricanes by smoothing things out with the neighbors. SA

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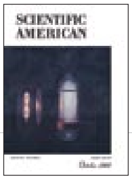
Illustration by Matt Collins



October 1960

Jab Fight

"By next spring a live-virus vaccine against poliomyelitis will be in limited but regular use in the U.S. Licenses will be granted to manufacturers, as each qualifies, for commercial production of the vaccine developed by Albert B. Sabin of the University of Cincinnati. The licensing of the Sabin vaccine caps 10 years of heated controversy between supporters of live-virus vaccines and those who have favored killed-virus vaccines of the Salk type. Advocates of live-virus vaccines have contended that a vaccine containing living polio viruses attenuated to eliminate risk of paralysis would give longer lasting, more certain protection against paralytic polio than a killed vaccine, and that live-virus vaccine would be simpler to administer because it can be given by mouth. (The Salk preparation must be injected.)"

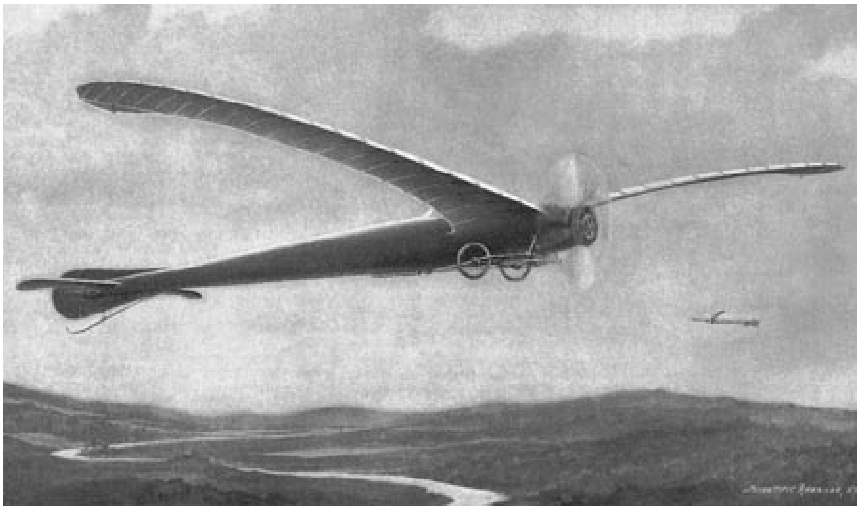
NOTE: *The Sabin version became the standard vaccine in the U.S. for the next four decades. As of about 2000, however, an updated version of the Salk vaccine is currently the only one given.*

October 1910

Racing Airplane

"It is possible to predict with some degree of certainty the leading characteristics of the aeroplane of the future which will be built purely for racing purposes. The speed of the aeroplane in straight-away flight has risen during the past year from 50 to 75 miles an hour. In answer to the question as to what speed may be expected from a machine of this general design, we think that in view of its sweetness of form, the complete absence of wires, struts and other energy consuming surfaces, and because of the smoothness of the steel surface of its skin, it is conservative to expect from such a machine speeds of from 100 to 125 miles an hour."

NOTE: *This article is available in full on the Web at www.ScientificAmerican.com/oct2010*

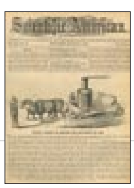


Racing airplane of the future, as conceived in 1910

SCIENTIFIC AMERICAN, VOL. CIII, NO. 17; OCTOBER 22, 1910

Wasted Seaweed

"It is evident that seaweeds are not quite as useless as they are usually supposed to be. Japan alone among nations prevents the exhaustion of its seaweed resources, and engages in 'seaweed farming' in order to supply the demand for certain species. Experimental planting on a small scale has been undertaken by the government, with encouraging results. In other sections of the coast seaweeds are extensively 'planted,' the variety employed being the red laver (*Porphyra laciniata*). This is manufactured into a great variety of food products. Its cultivation is one of the most profitable branches of agriculture."



October 1860

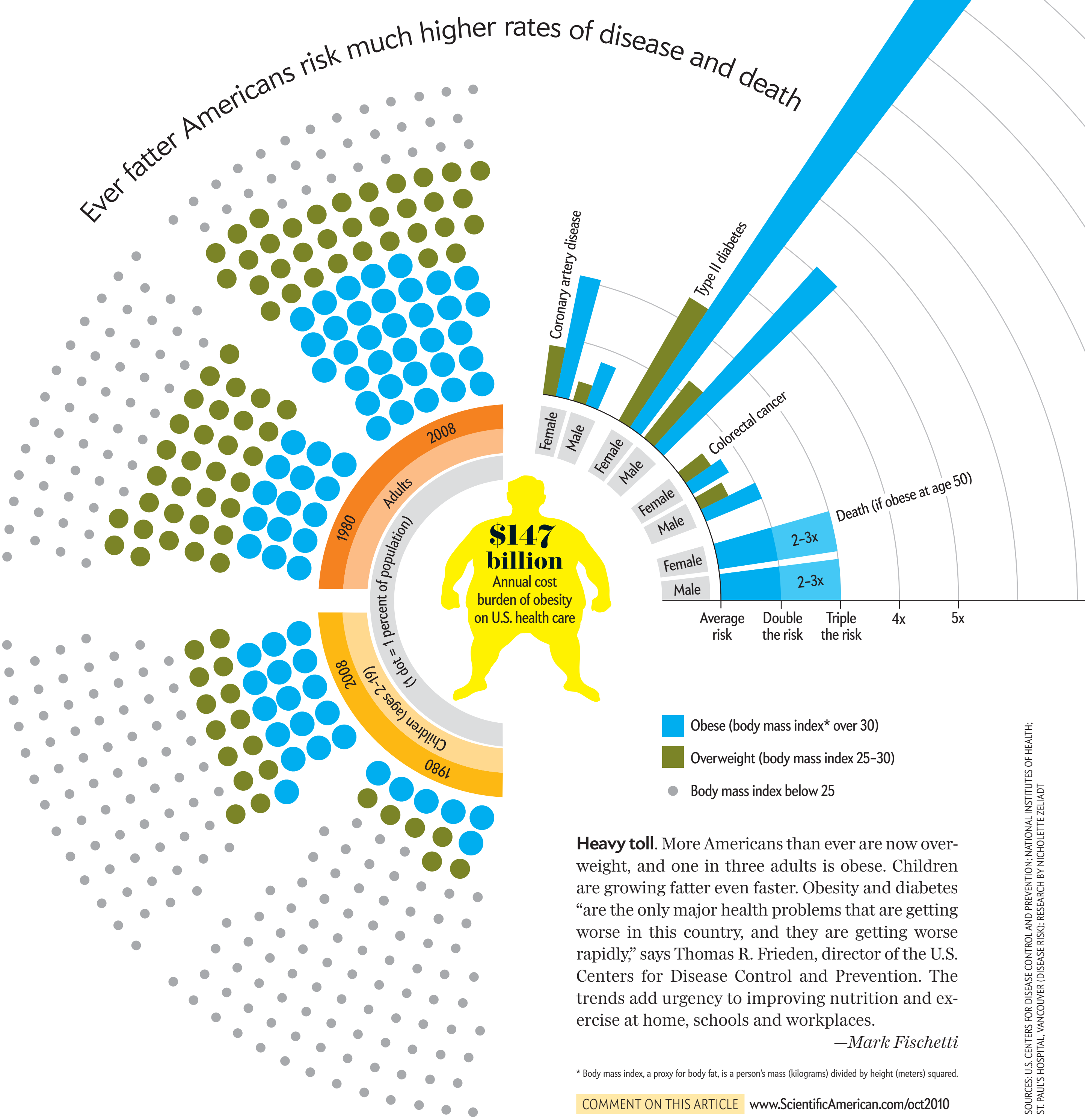
End of the Earth

"Encke's comet, which revolves about the sun in 3½ years, has been observed to complete its revolution in a constantly shortening period, showing that it is being drawn inward towards the sun. This fact has led to the general conclusion that the planets are moving in a resisting medium, far more attenuated than our atmosphere, but still sufficient to affect their motions. It follows by strict necessity that our earth and its sister orbs are all winding spirally towards the sun, and that they must eventually strike against it and become incorporated with its mass. The time required for this fate belongs to those inconceivable periods with which geology and astronomy have to deal."

Against Homework

"A child who has been boxed up six hours in school might spend the next four hours in study, but it is impossible to develop the child's intellect in this way. The laws of nature are inexorable. By dint of great and painful labor, the child may succeed in repeating a lot of words, like a parrot, but, with the power of its brain all exhausted, it is out of the question for it to really master and comprehend its lessons. The effect of the system is to enfeeble the intellect even more than the body. We never see a little girl staggering home under a load of books, or knitting her brow over them at eight o'clock in the evening, without wondering that our citizens do not arm themselves at once with carving knives, pokers, clubs, paving stones or any weapons at hand, and chase out the managers of our common schools, as they would wild beasts that were devouring their children." SA

Dying to Eat



Heavy toll. More Americans than ever are now overweight, and one in three adults is obese. Children are growing fatter even faster. Obesity and diabetes "are the only major health problems that are getting worse in this country, and they are getting worse rapidly," says Thomas R. Frieden, director of the U.S. Centers for Disease Control and Prevention. The trends add urgency to improving nutrition and exercise at home, schools and workplaces.

—Mark Fischetti

* Body mass index, a proxy for body fat, is a person's mass (kilograms) divided by height (meters) squared.

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/oct2010

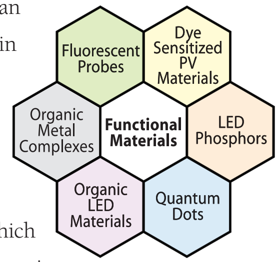
SOURCES: U.S. CENTERS FOR DISEASE CONTROL AND PREVENTION; NATIONAL INSTITUTES OF HEALTH; ST. PAUL'S HOSPITAL, VANCOUVER (DISEASE RISK); RESEARCH BY NICHOLETTE ZELIADT

Graphic by Jen Christiansen

Advances in fluorescent spectrometry make it easier to tailor new functional materials...

Higher-precision analysis, faster

Functional materials are unique substances that can sense environmental changes, such as temperature, pressure, electric fields, pH and much more. And by analyzing the fluorescent spectrum of such a material, a scientist can tailor its capabilities in many useful ways.

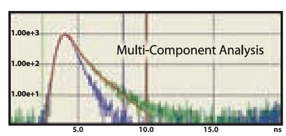


The problem is that a functional material may contain multiple elements, which confuses the spectroscopic analysis. So Hamamatsu created a solution...

Quantaurus is a new class of spectroscopic analyzers that can distinguish a material's component elements by measuring variations in the

Hamamatsu is opening the new frontiers of Light

fluorescence lifetime, often at sub-nanosecond levels. Another Quantaurus model provides even more detail by measuring the absolute photo-luminescence quantum yield.



Separating fluorescence lifetimes of components in a functional material.

All of these new analyzers are very fast. And very *automated*. Virtually anyone can use them. Making it easier to put more functionality into functional materials. For everything from solar cells to organic LED illumination, quantum dots to fluorescent proteins.

It's one more way Hamamatsu is opening the new frontiers of light. For science and for you.

http://jp.hamamatsu.com/en/rd/publication/

HAMAMATSU

Photon is Our Business

Hamamatsu's new Quantaurus series of advanced spectroscopic analyzers is able to measure variations in *fluorescence lifetime*, which is the length of time between a material's excitation by a light source and return to its ground state.